Particle Detectors.
Part 2

Lectures at the CHIPP PhD Winter School 2012
Christoph Rembser (CERN)

Outline of this 2. lecture

- Detectors for particle physics - an overview
- Particle interactions with matter
- Tracking detectors
- Calorimeters
- Detectors for particle identification and triggering
- Interleaved with examples of detectors and experiments as well as lessons from real life

Thank you for yesterdays comments and feedback!!!

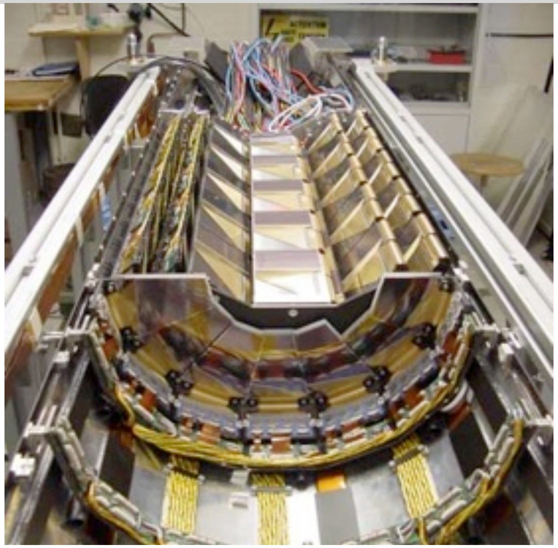
Tracking detectors

Semiconductor detectors

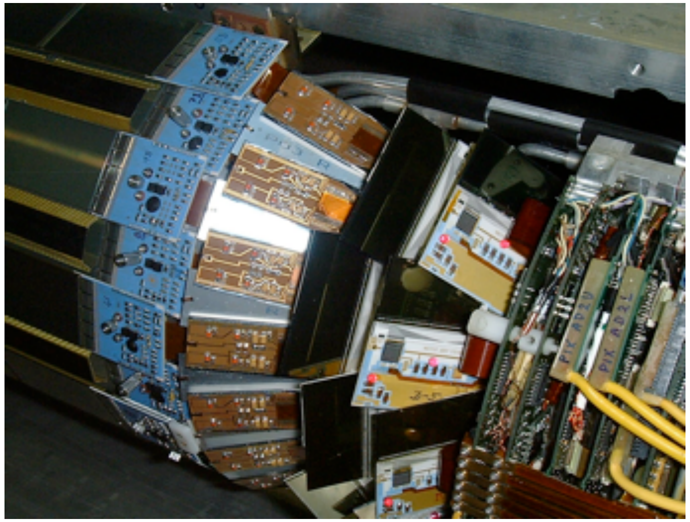
Brief History

- ~1950: Discovery that pn-Junctions can be used to detect particles.
  - Semiconductor detectors used for energy measurements (Germanium)
- Since ~ 30 years: Semiconductor detectors for precise position measurements.
  - precise position measurements possible through fine segmentation (10-100μm)
  - multiplicities can be kept small (goal:<1%)

- Technological advancements in production technology:
  - developments for micro electronics

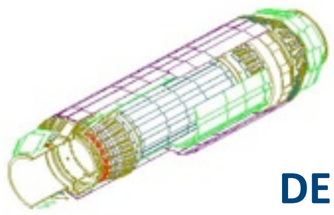


ZEUS MVD 2000



DELPHI VFT 1996

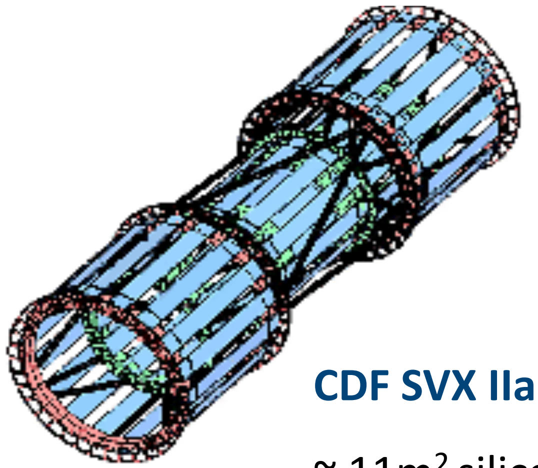
Semiconductor detectors are growing...



DELPHI (1996)

~ 1.8m^2 silicon area

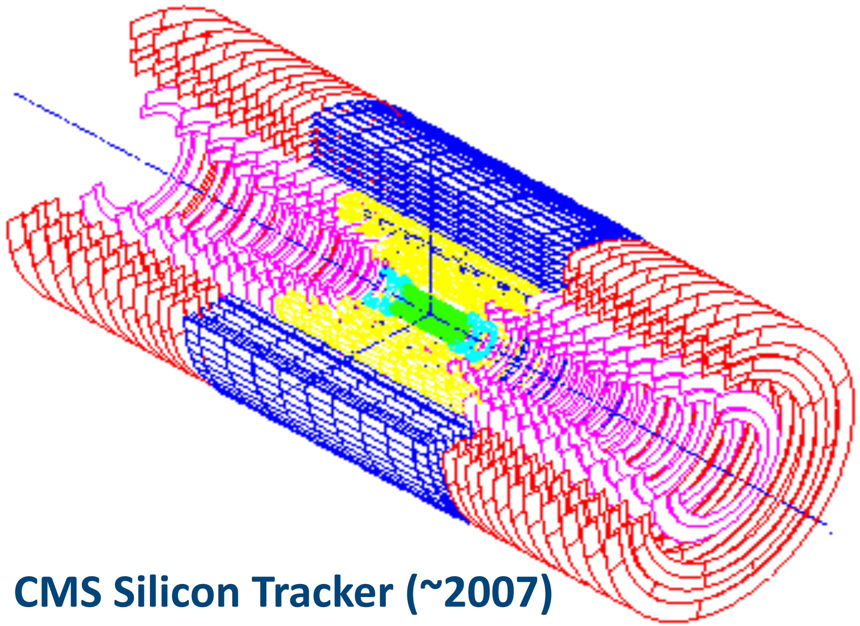
~ 175 000 readout channels



CDF SVX IIa (2001-2011)

~ 11m^2 silicon area

~ 750 000 readout channels



CMS Silicon Tracker (~2007)

~12,000 modules

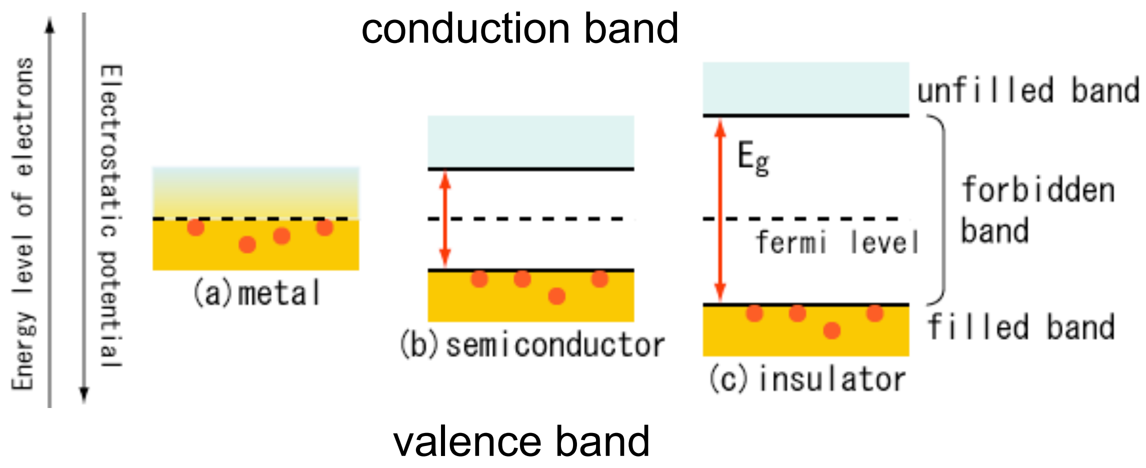
~ 223 m^2 silicon area

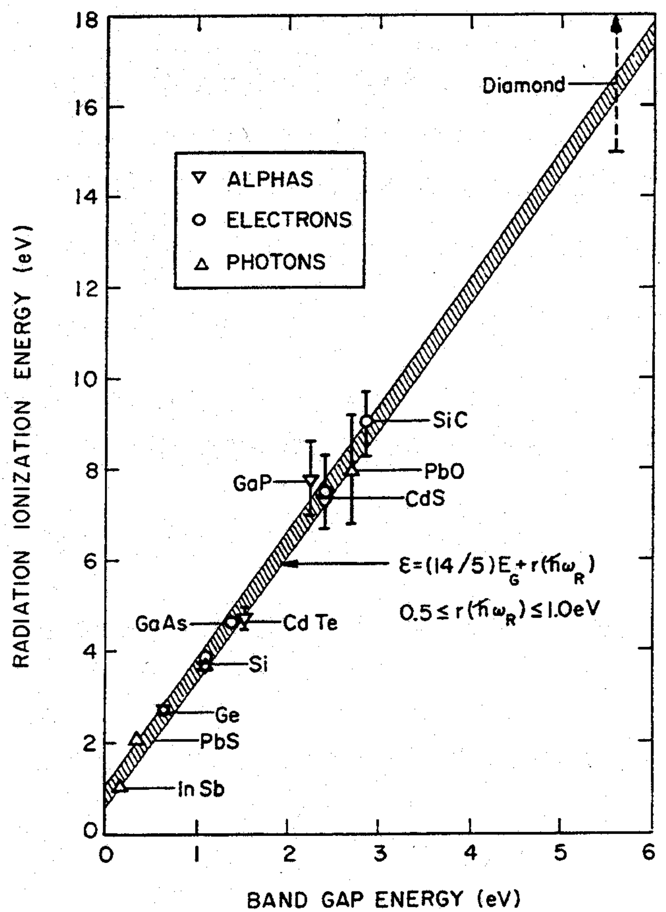
~25,000 silicon wafers

~ 10M readout channels

Semiconductor basics

- In free atoms the electron energy levels are discrete.
- In a solid, energy levels split and form a nearly-continuous band.

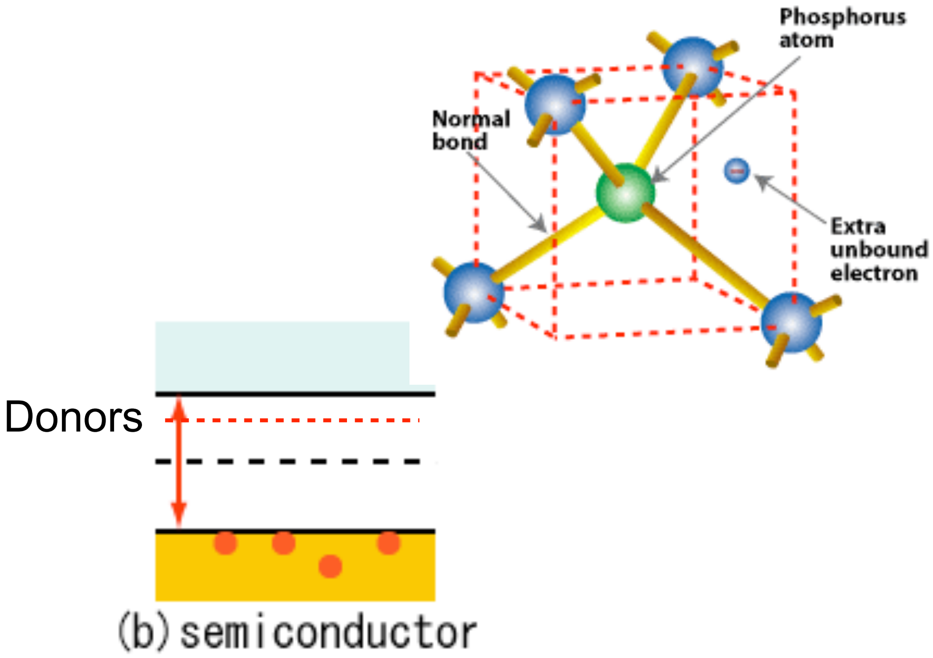


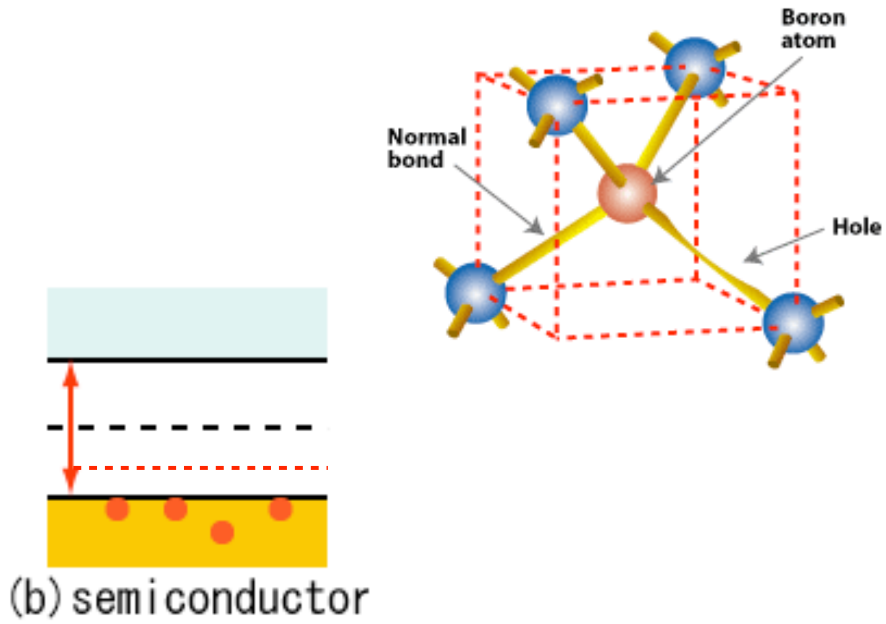


- Large gap: the solid is an insulator.
- No gap: it is a conductor.
- Small band gap: semiconductor

- For silicon, the band gap is 1.1 eV, but it takes 3.6 eV to ionise an atom. The rest of the energy goes to phonon excitations (heat).

Doping Silicon





n-type:

◎ In an n-type semiconductor, negative charge carriers (electrons) are obtained by adding impurities of donor ions (eg. Phosphorus (type V))

◎ Donors introduce energy levels close to conduction band thus almost fully ionized

Electrons are the majority carriers.

p-type:

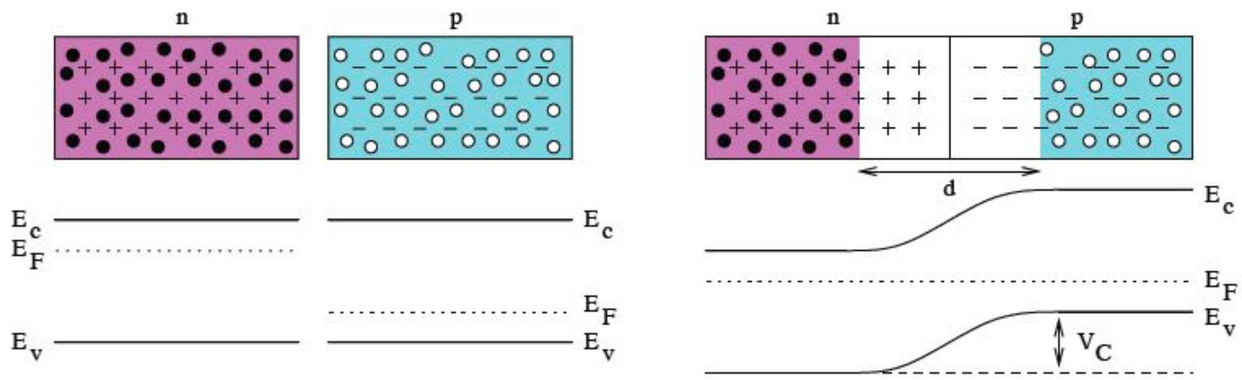
◎ In a p-type semiconductor, positive charge carriers (holes) are obtained by adding impurities of acceptor ions (eg. Boron (type III))

◎Acceptors introduce energy levels close to valence band thus 'absorb' electrons from VB, creating holes

Holes are the majority carriers.

PN-Junction

- p- and n-doted semiconductor combined
- Gradient of electron and hole densities results in a diffuse migration of majority carriers across the junction.
- Migration leaves a region of net charge of opposite sign on each side, called the depletion region (depleted of charge carriers).



- Artificially increasing this depleted region by applying a reversed **bias voltage** allow charge collection from a larger volume

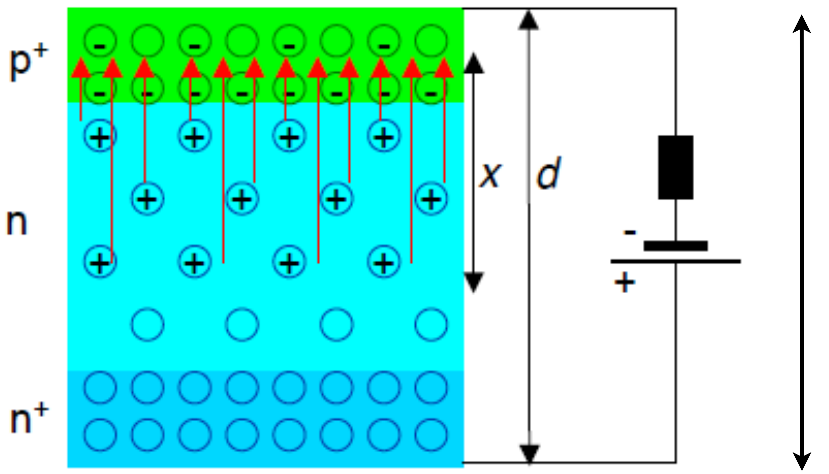
$$d = \sqrt{\frac{2\epsilon\epsilon_0 V}{e}\left(\frac{1}{n_D} + \frac{1}{n_A}\right)} \quad \text{with} \quad n_A >> n_D \quad d = \sqrt{\frac{2\epsilon\epsilon_0 V}{e n_D}}$$

Principle of semiconductor detectors

1. Creation of electric field:
   voltage to deplete thickness d

$$V_{\text{dep}} = d^2 N_{\text{eff}} \frac{q}{2\epsilon\epsilon_0}$$

N_{eff} : doping concentration



in “classical” HEP detectors 100-300 um

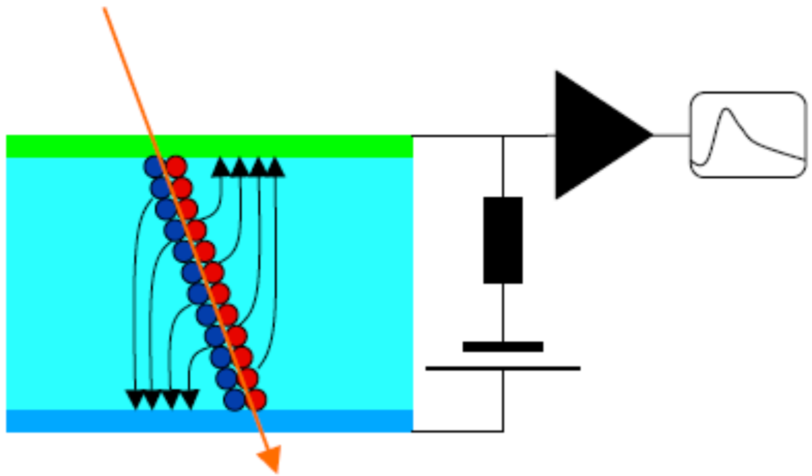
2. Keep dark current low

$$I \propto \frac{1}{\tau_g} \cdot T^2 \exp - \frac{E_g}{2kT} \times \text{volume}$$

τ_g : charge carrier life time

3. Ionising particles create free charge carrier

4. Charge carrier drift to electrodes and induce signal

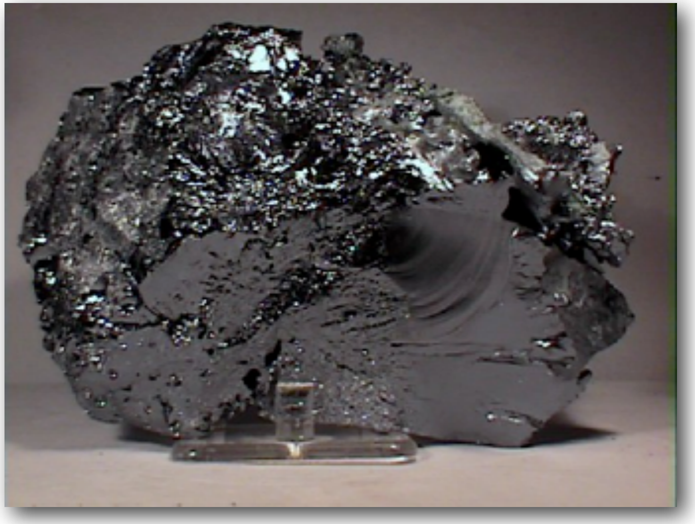


Material properties

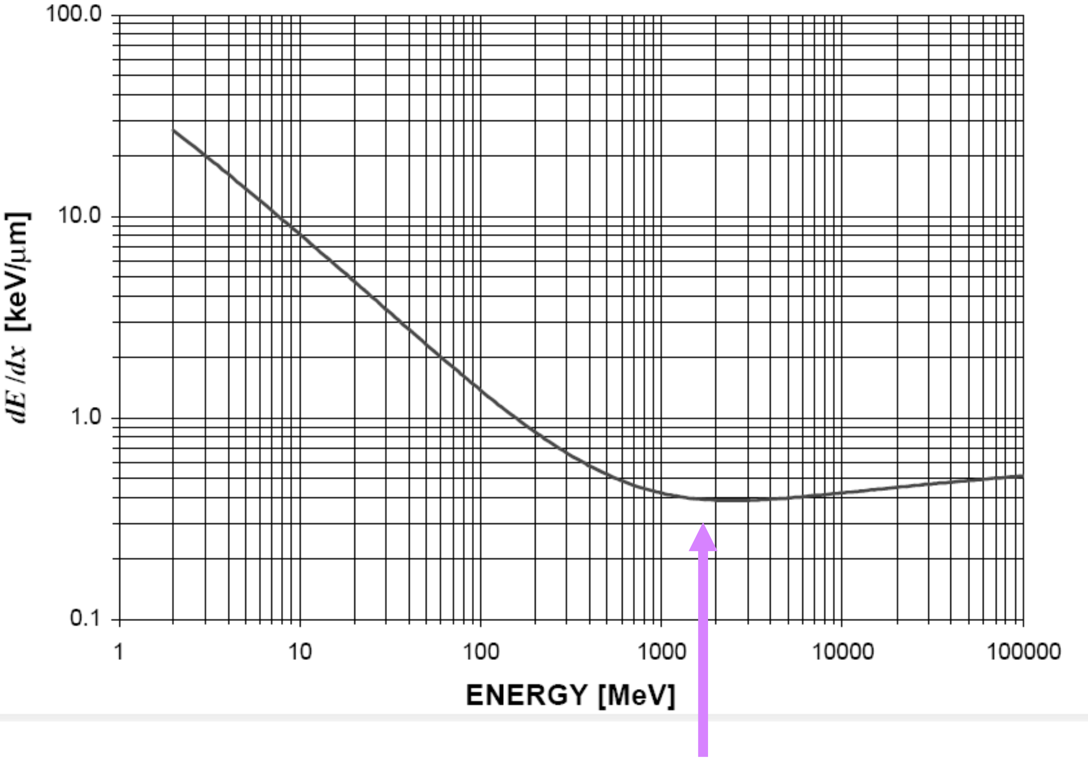
	Si	Ge	GaAs	CdTe	Diamant	SiC
band gap	1.12	0.67	1.42	1.56	5.48	2.99
energy for e-p pair [eV]	3.6	2.9	4.2	4.7	13.1	6.9
e- for MIP (300µm)	24000	50000	35000	35000	9300	19000
Z	14	32	31+33	48+52	6	14+6

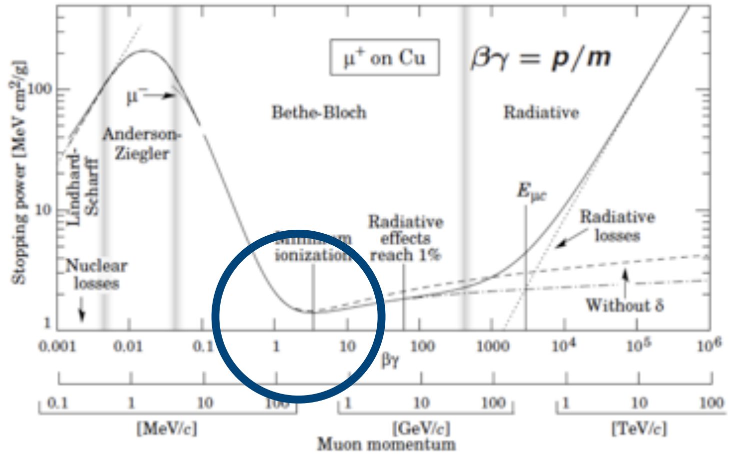
Why is silicon used more often ?

- Silicon is the only material which can be produced in larger wafers in high quality
- compare to kT = 0.026 eV at room temperature -> dark current under control
- high density compared to gases: ρ=2.33g/cm^3
- good mechanical stability -> possible to produce mechanically stable layers
- large charge carrier mobility
- fast charge collection δt~10ns



Protons in Silicon





MIP energy loss of 0.4 keV/µm

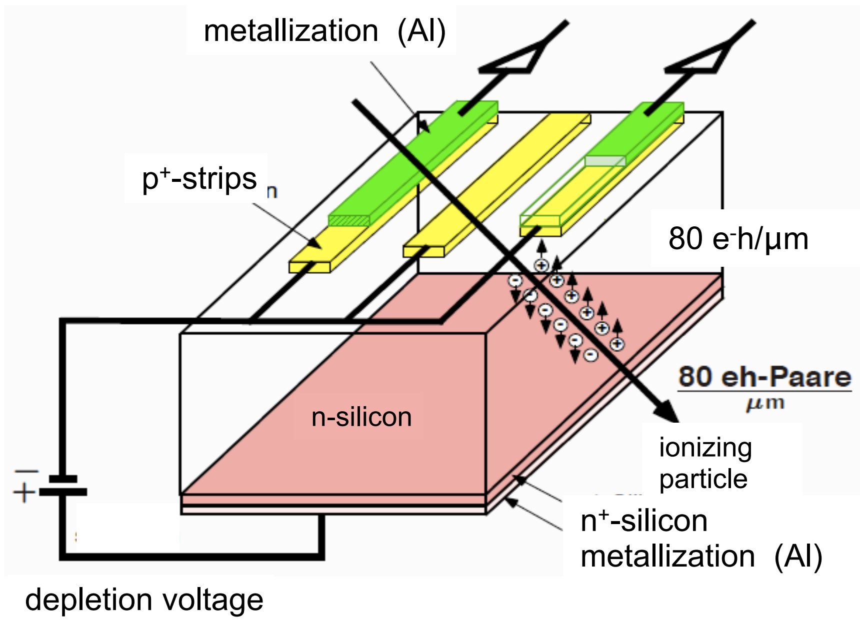
with 3.6 eV to create an electron hole pair (see table on previous slide):

~110 electron-hole pairs per µm (mean value), thus

most probably number of electrons for a MIP proton and µm of SI: 80

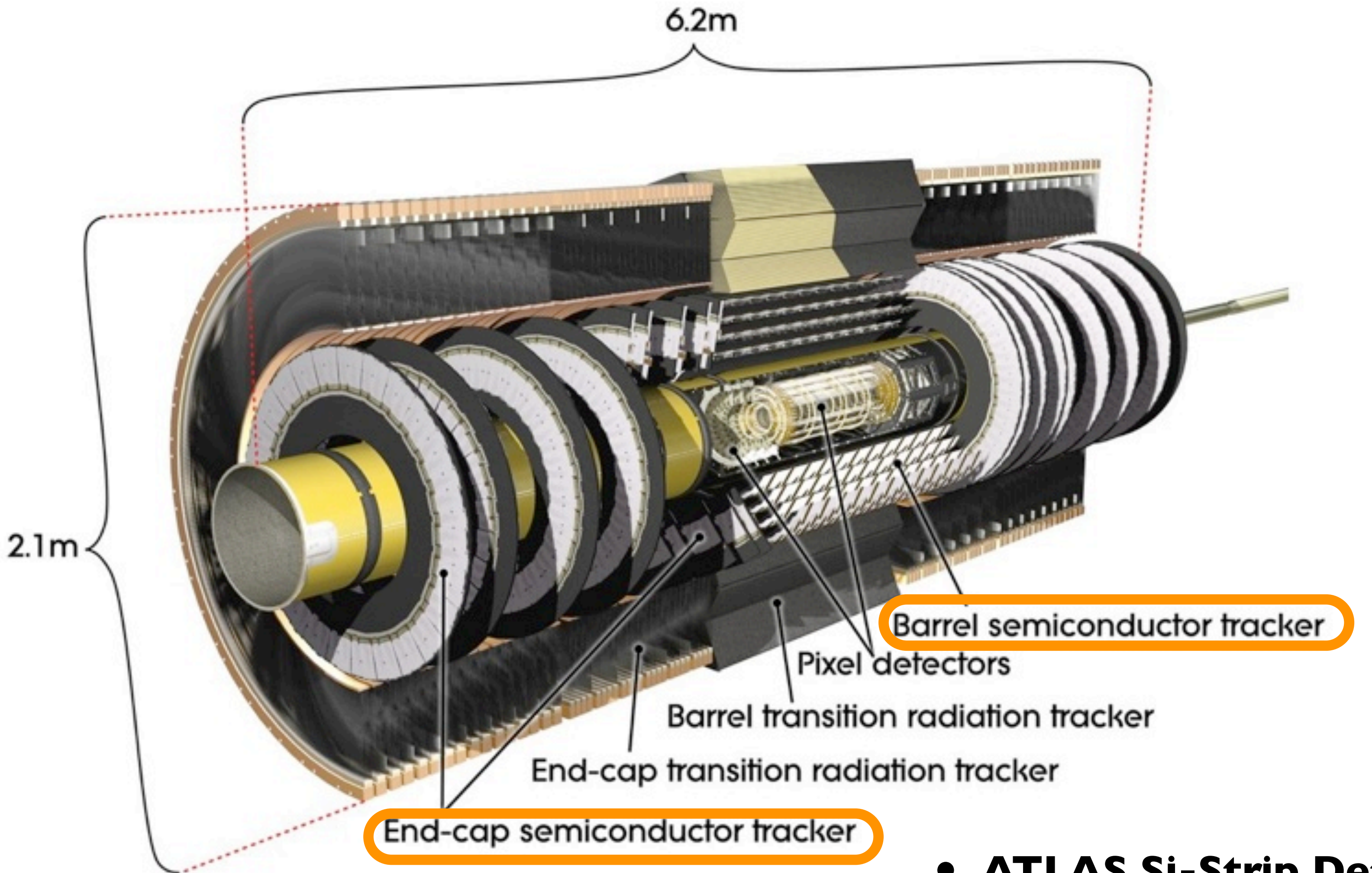
Strip detectors

- First detector devices using the lithographic capabilities of microelectronics
- First Silicon detectors -> strip detectors
- Can be found in all high energy physics experiments of the last 25 years



- Arrangement of strip implants acting as charge collecting electrodes.
- Placed on a low doped fully depleted silicon wafer these implants form a one-dimensional array of diodes
- By connecting each of the metalised strips to a charge sensitive amplifier a position sensitive detector is built.
- Two dimensional position measurements can be achieved by applying an additional strip like doping on the wafer backside (double sided technology)

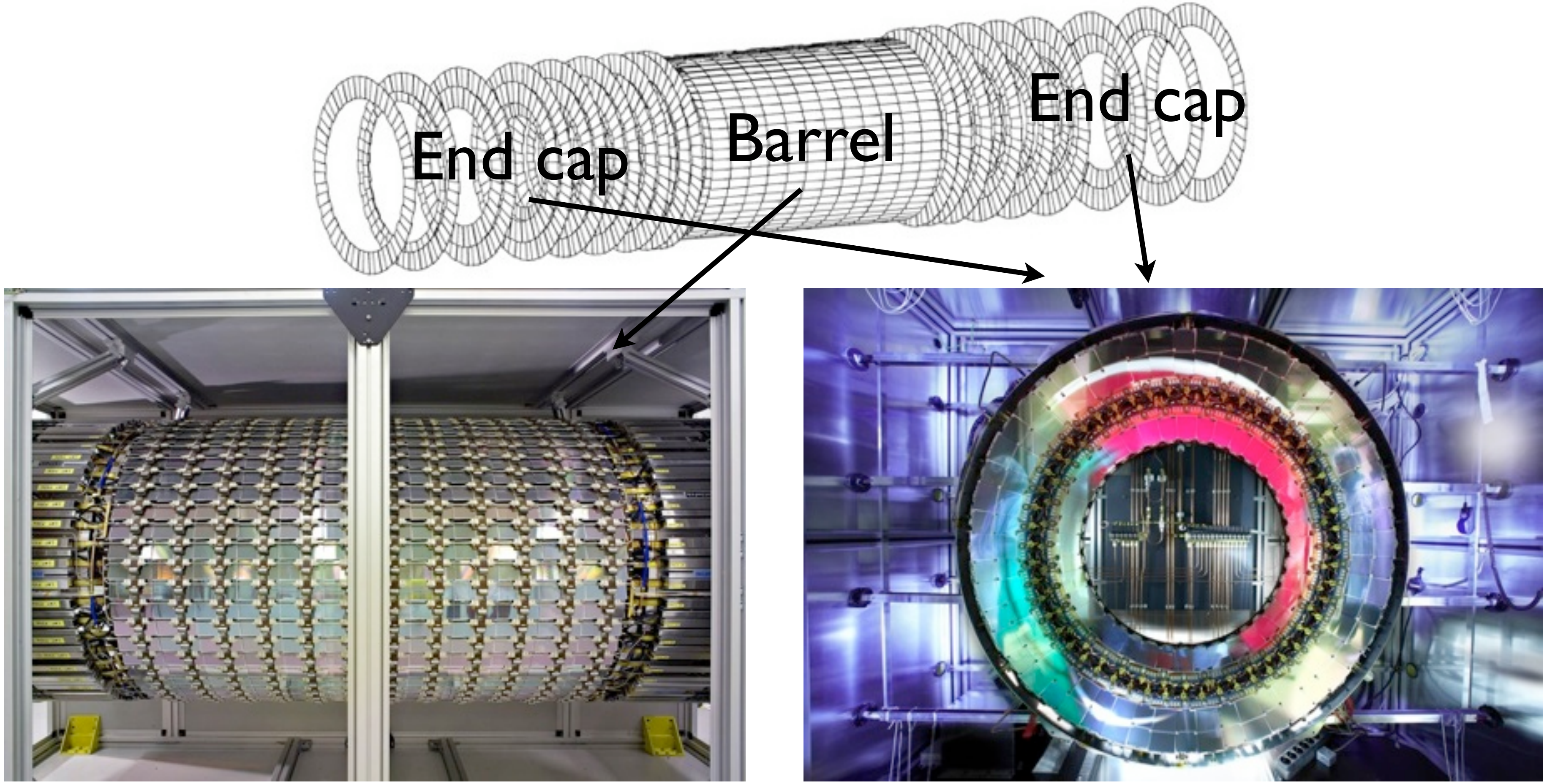
ATLAS Strip Detector



- **ATLAS Si-Strip Detector SCT** (= **S**emi**C**onductor **T**racker)
  - ➡ 4 Barrel-layer, 2 x 9 discs

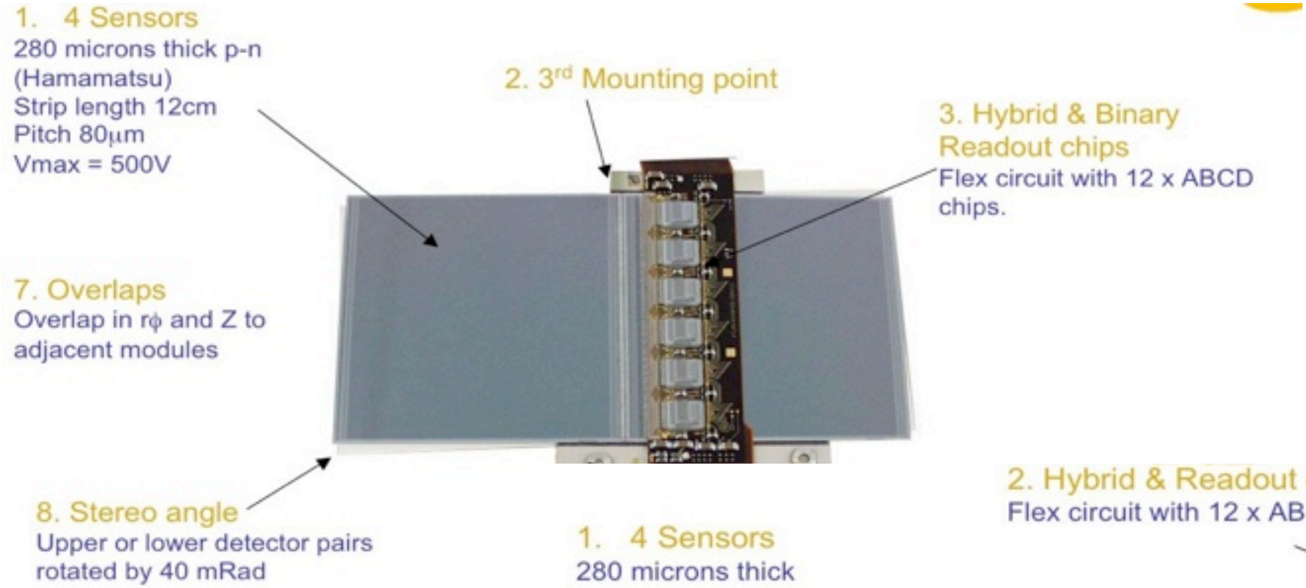
ATLAS SCT

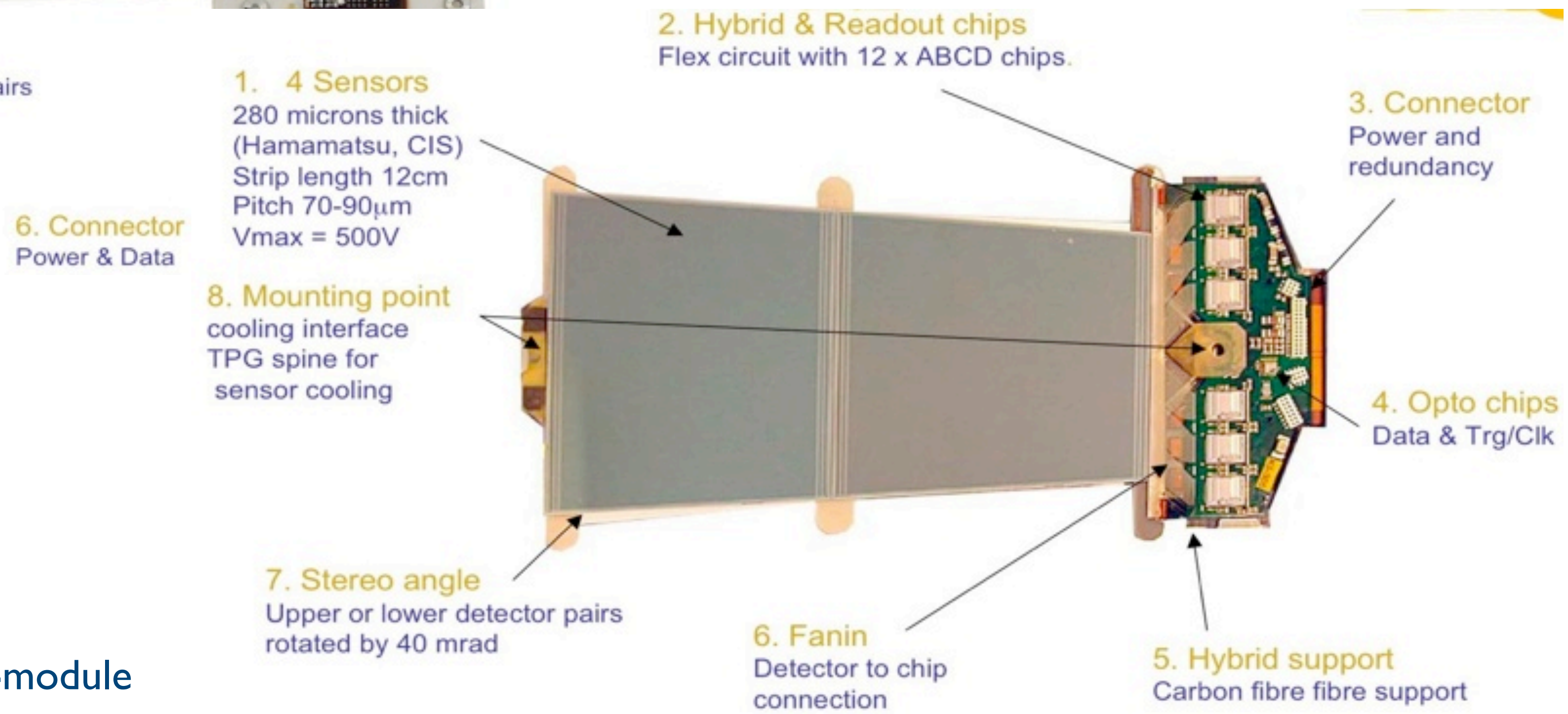
- SCT strips
  - ➡ 61 m^2 silicon, ~6.2 M channels
  - ➡ 4088 modules, 2112 barrel (1 type), 1976 in the discs (4 different types)



Example: the ATLAS SCT modules

barrel-module

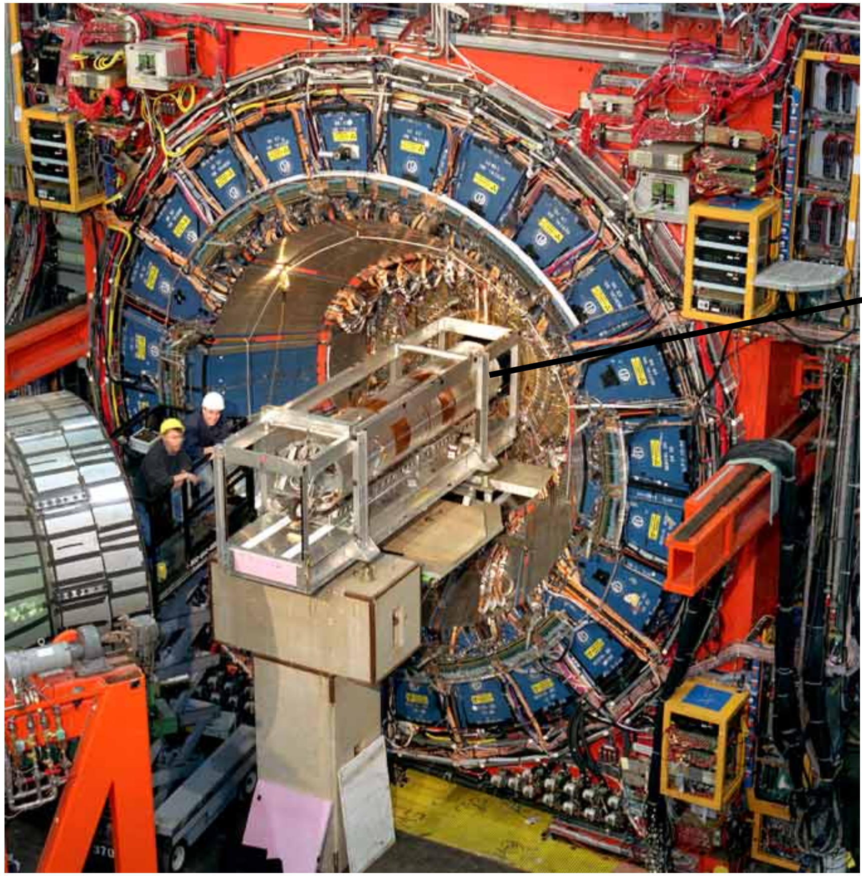


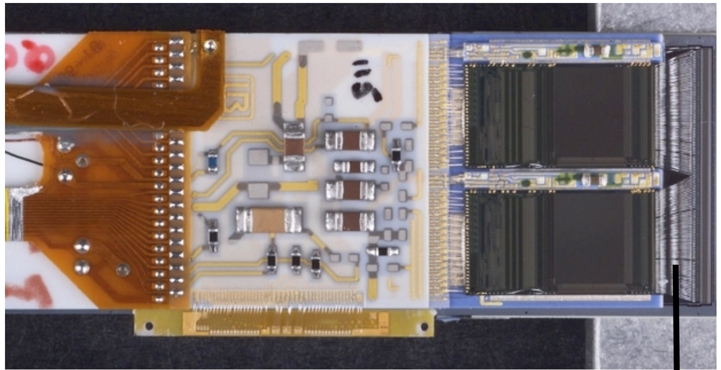


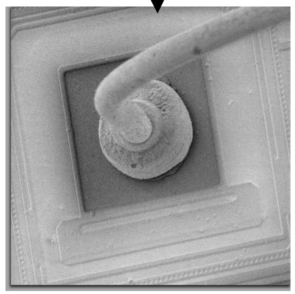
disc-module

Surprises happen...

During test pulse operation, Lorentz force on bonding wires (perpendicular to magnetic field) …





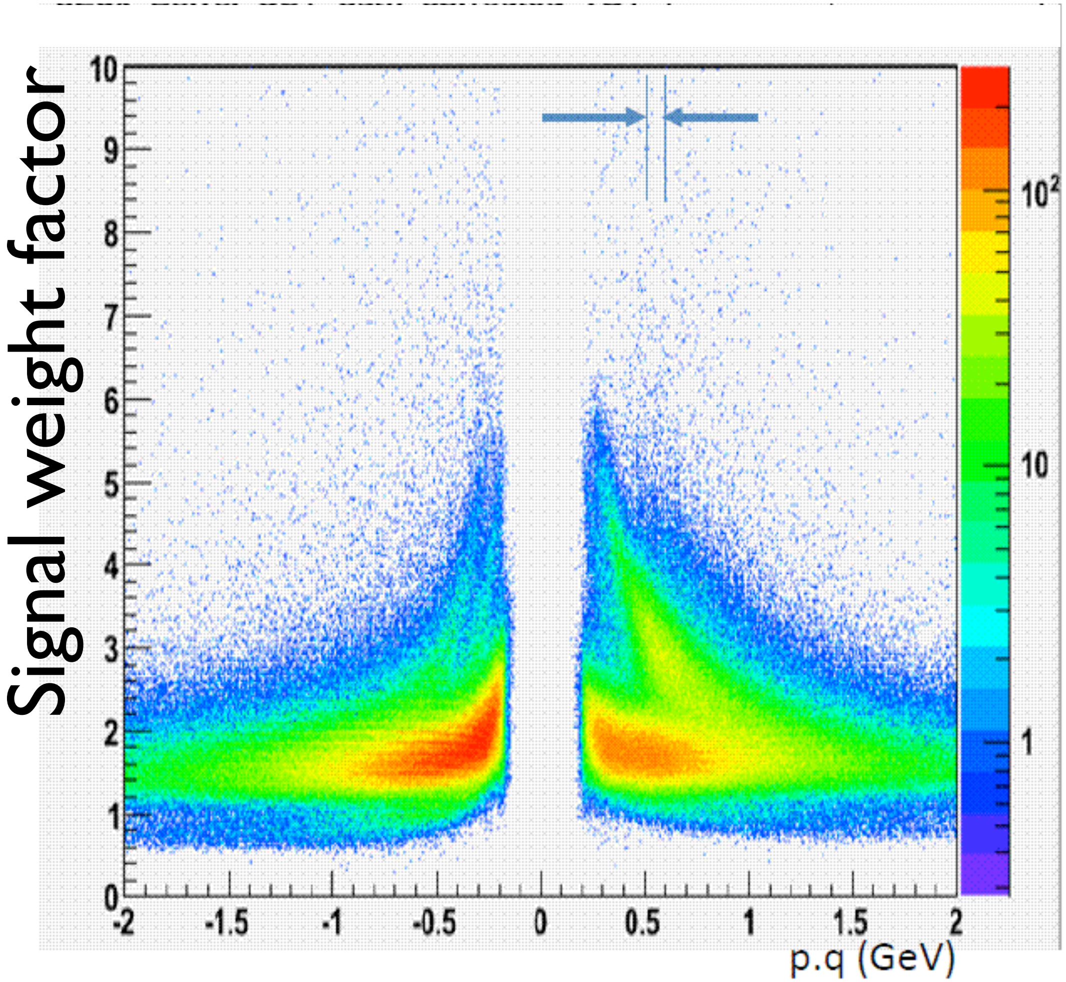


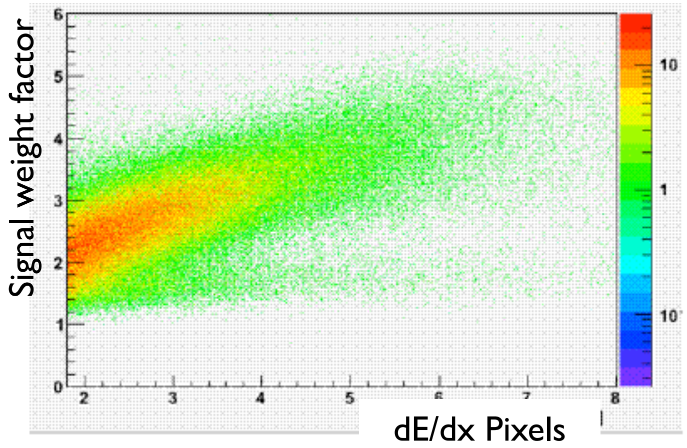
…breaks wire bonds between detector and read out.

...happened to 2 experiments!

Strip detector performance

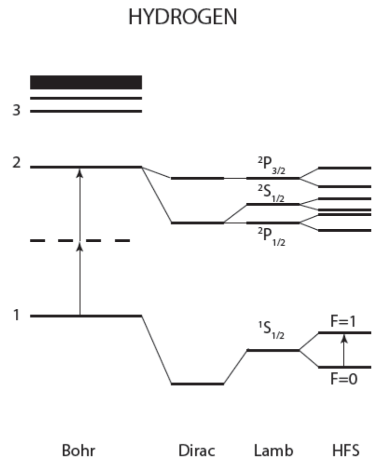
- Typical values of position resolution at the LHC: ~25 µm
- ...and - for surprise - particle ID works, too....

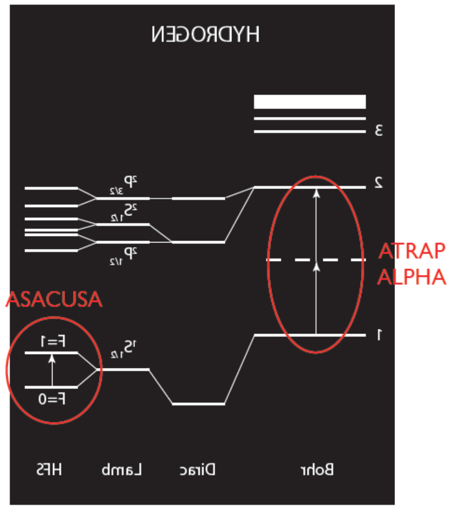




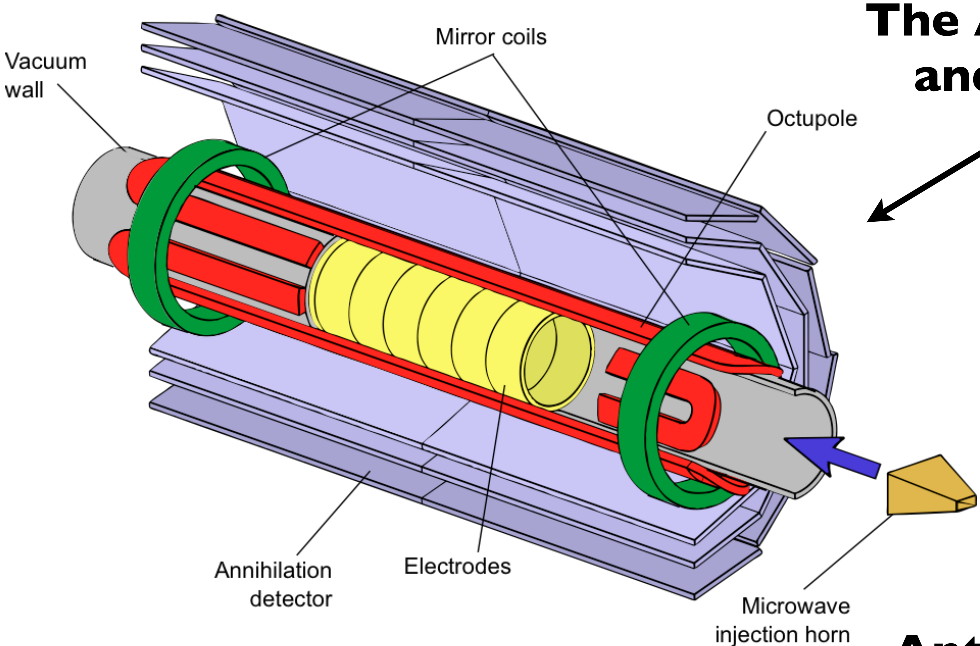
Important to have strips: ALPHA@AD

- Experiment at the CERN Antiproton Decelerator to study difference matter - antimatter using **spectroscopy**

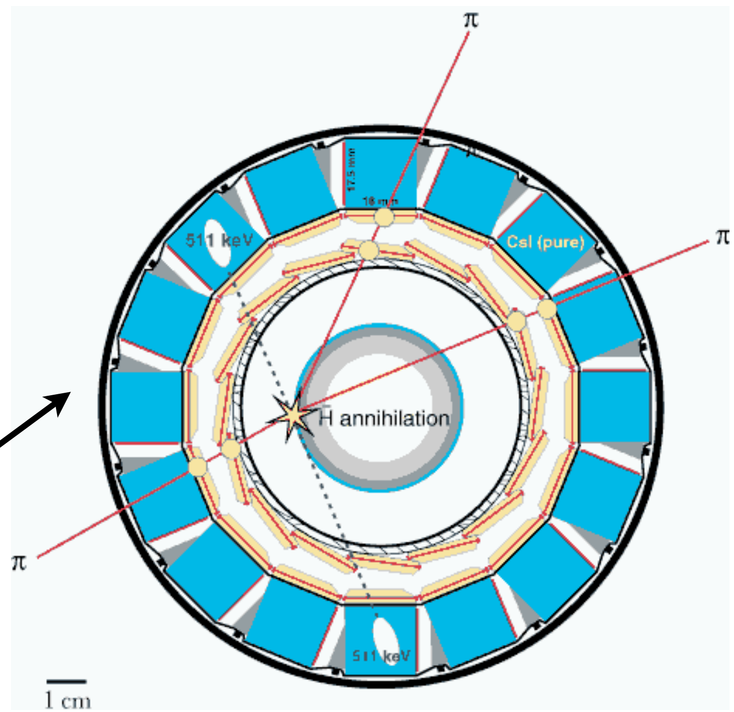




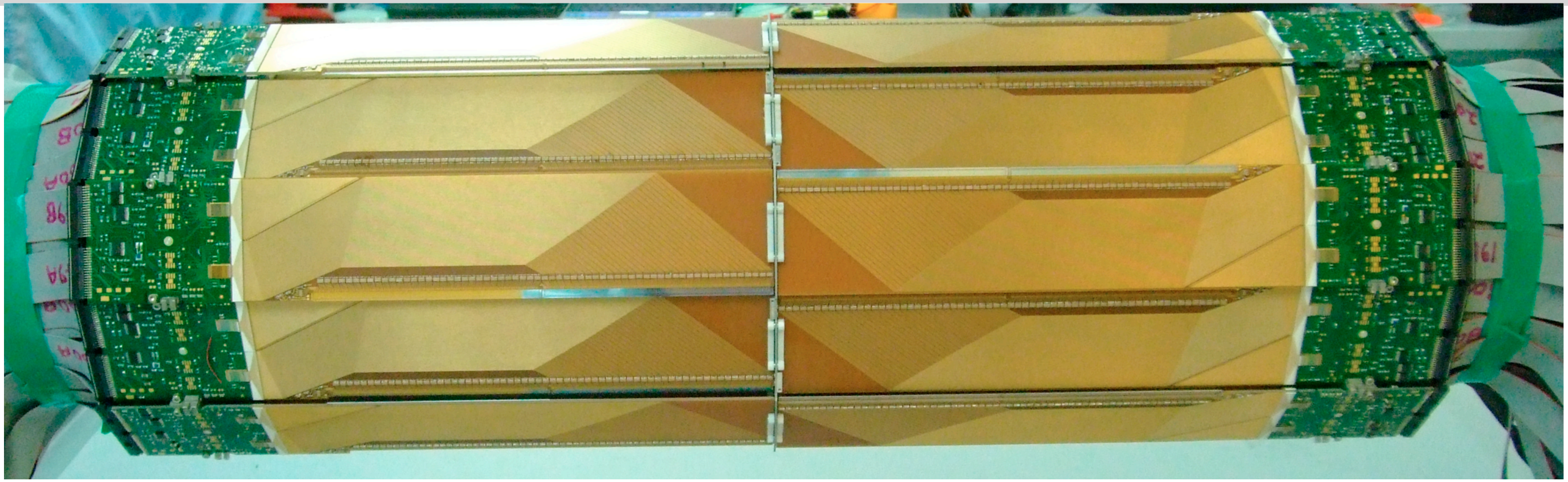
The ALPHA trap and detector



Anti-hydrogen annihilation

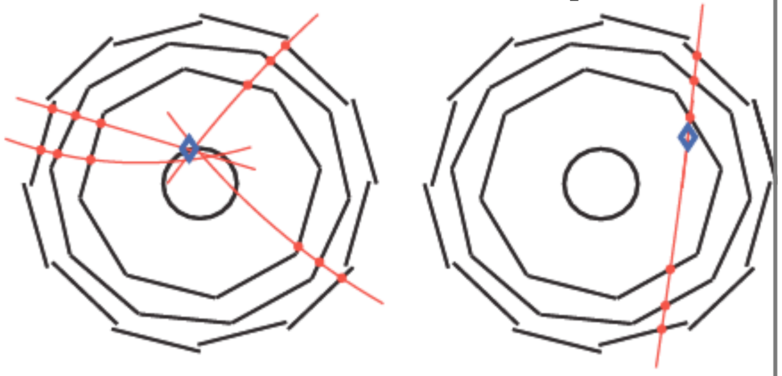


The ALPHA SI Vertex Detector



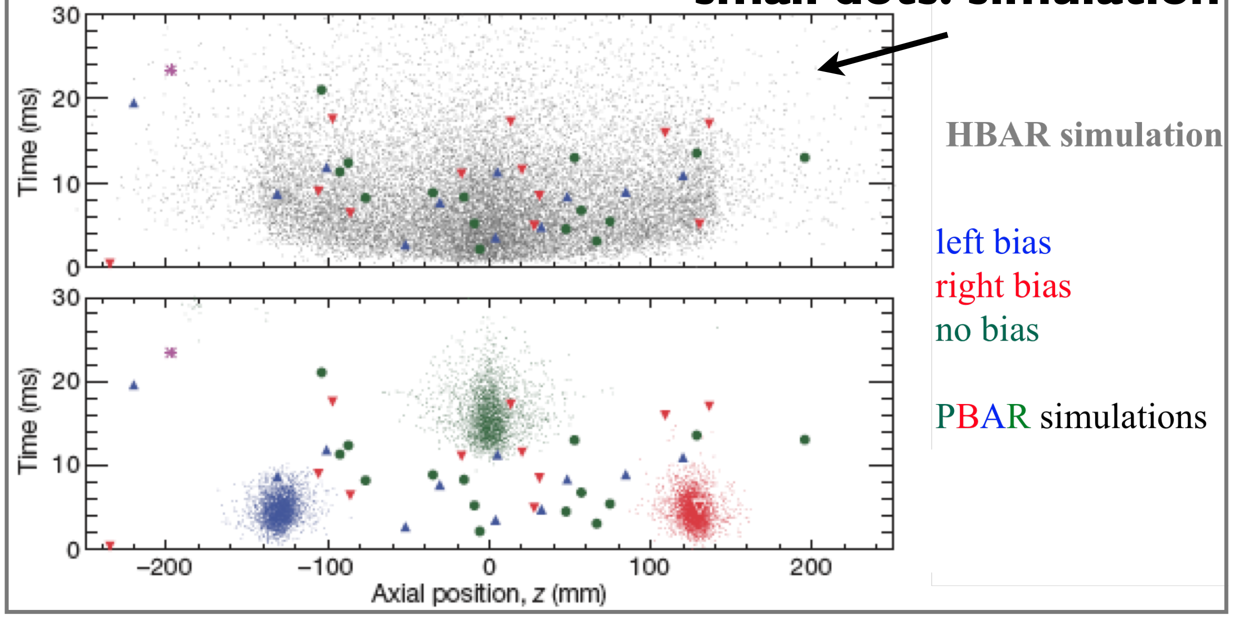
signal: annihilations

background: cosmic particles



Proof of trapping!!!

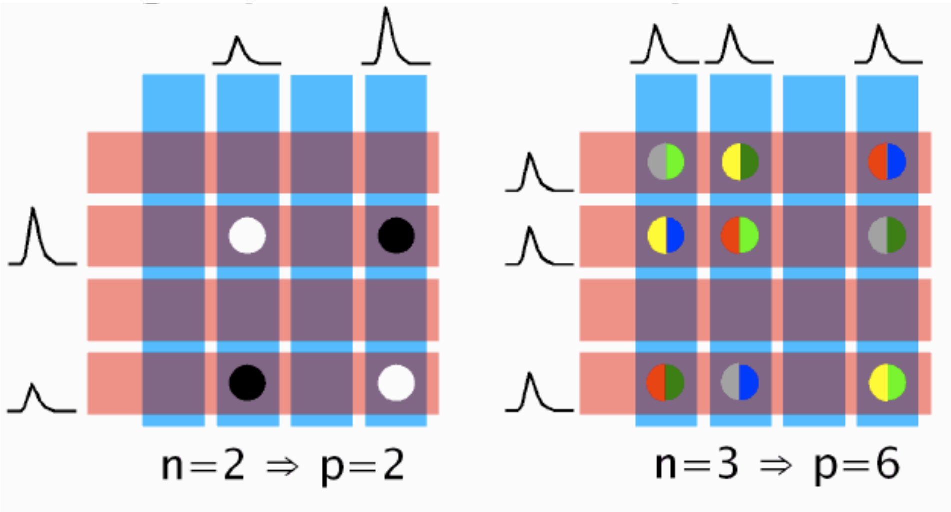
big dots: data
small dots: simulation



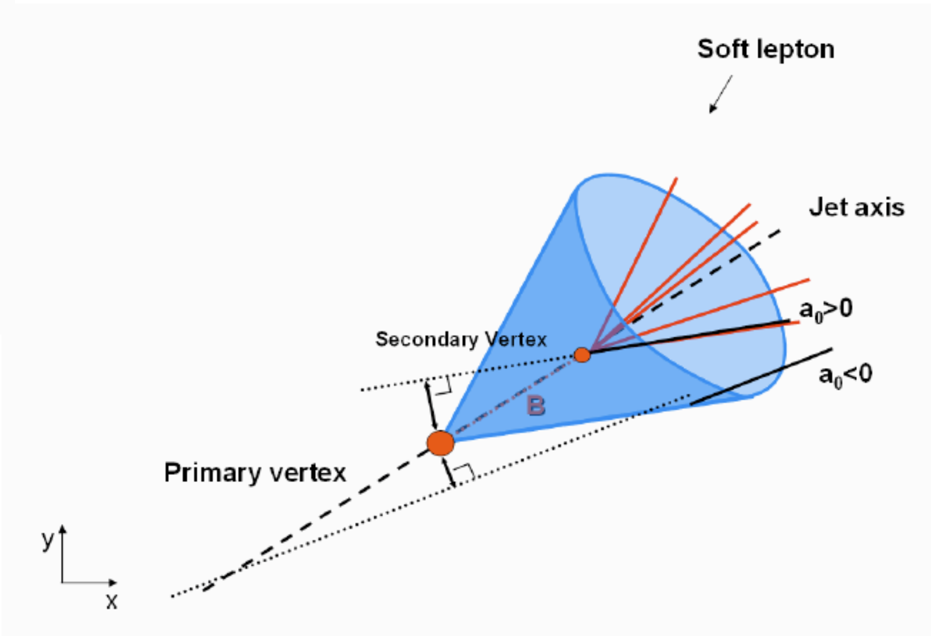
ALPHA: Trapping anti-hydrogen

Video: ALPHA Collaboration

Limits of strip detectors



- In case of high particle flux ambiguities give difficulties for the track reconstruction

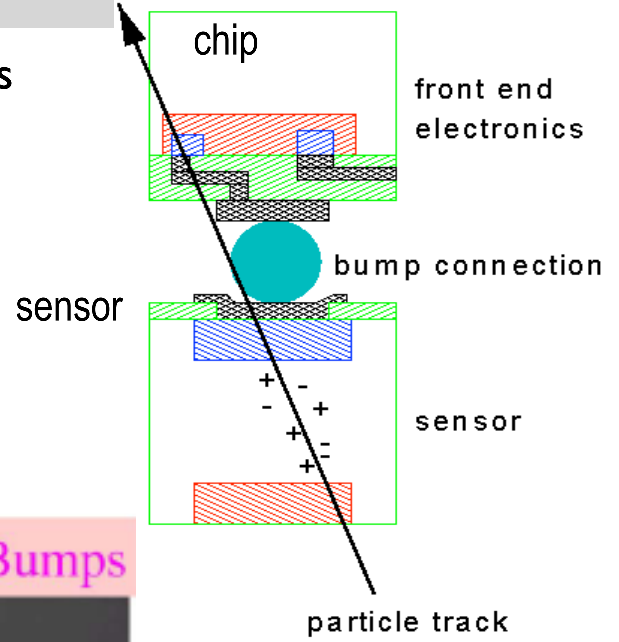


- Deriving the point resolution from just one coordinate is not enough information to reconstruct a secondary vertex

- **Pixel detectors** allow track reconstruction at high particle rate without ambiguities
- Good resolution with two coordinates (depending on pixel size and charge sharing between pixels)
- But: very high channel number - needs complex read-out
- Readout in active area a detector

First pixels (CCDs) in NA11/NA32: ~1983

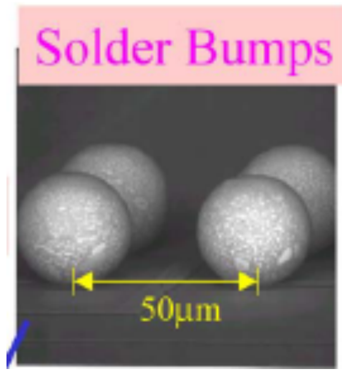
Hybrid pixels: the classical HEP choice

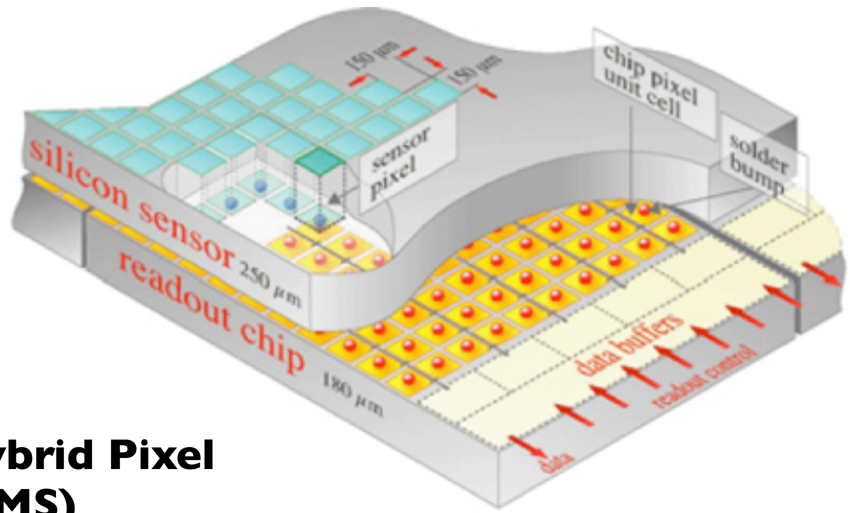


- The read-out chip is mounted directly on top of the pixels (bump-bonding)
- Each pixel has its own read-out amplifier

… but:

- Pixel area defined by the size of the read-out chip
- High material budget and high power dissipation

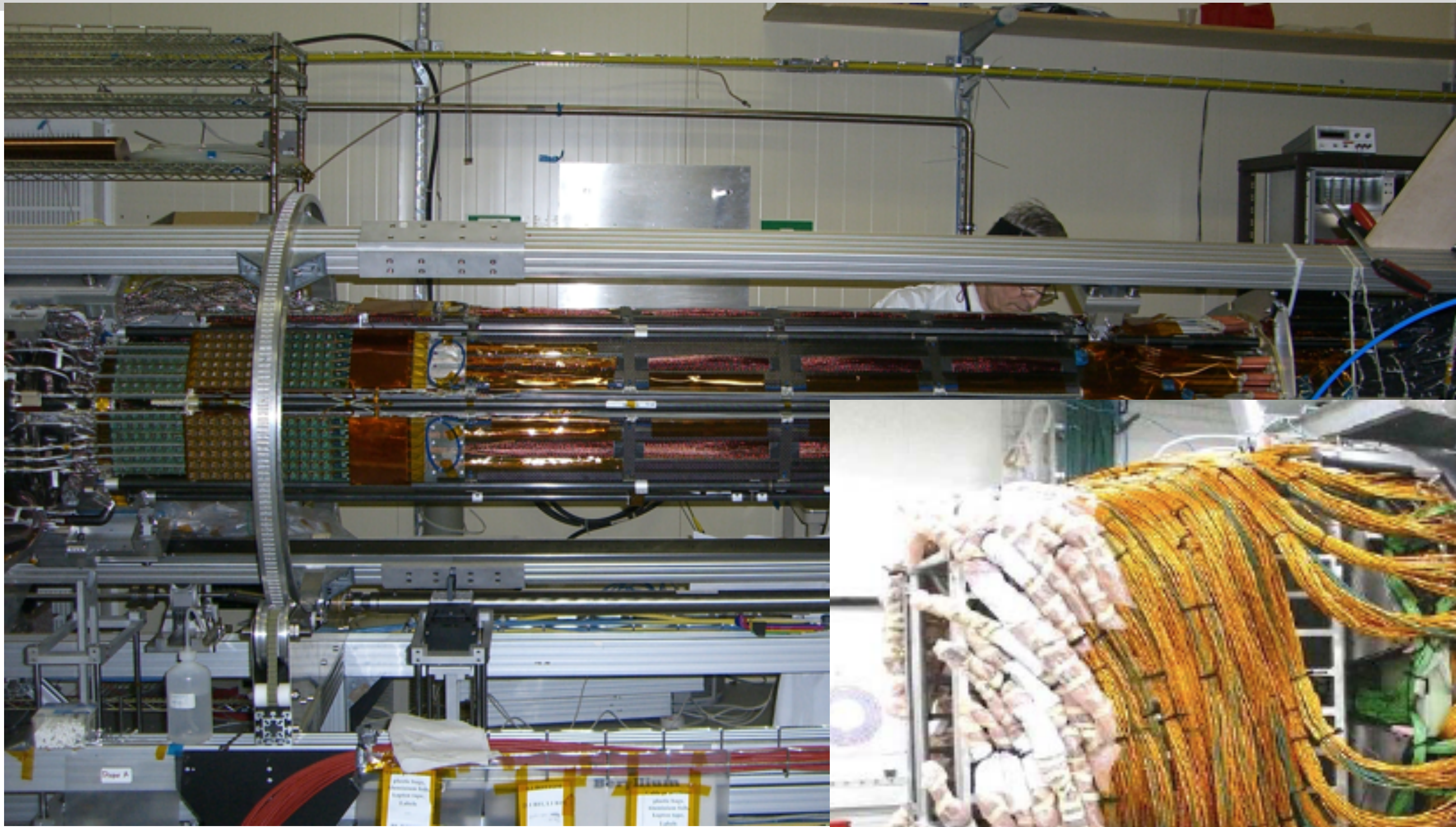


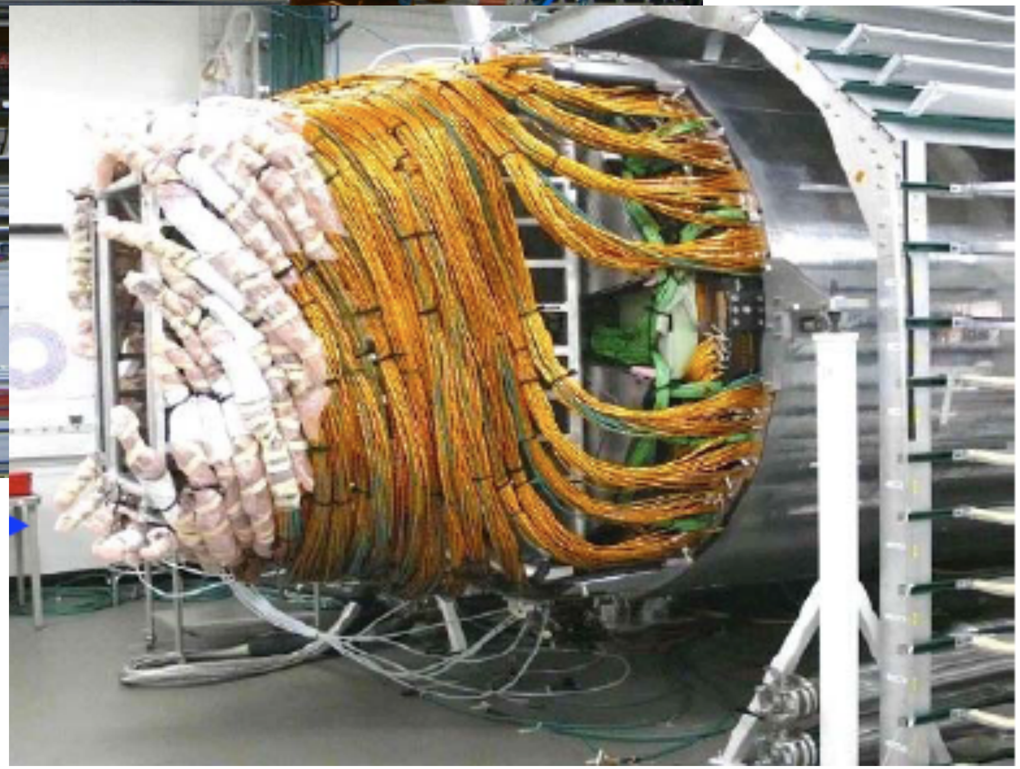


Hybrid Pixel (CMS)

- CMS Pixels: ~65 M channels 150 µm x 150 µm
- ATLAS Pixels: ~80 M channels 50 µm x 400 µm (long in z or r)
- ALICE: 50 µm x 425 µm
- ….

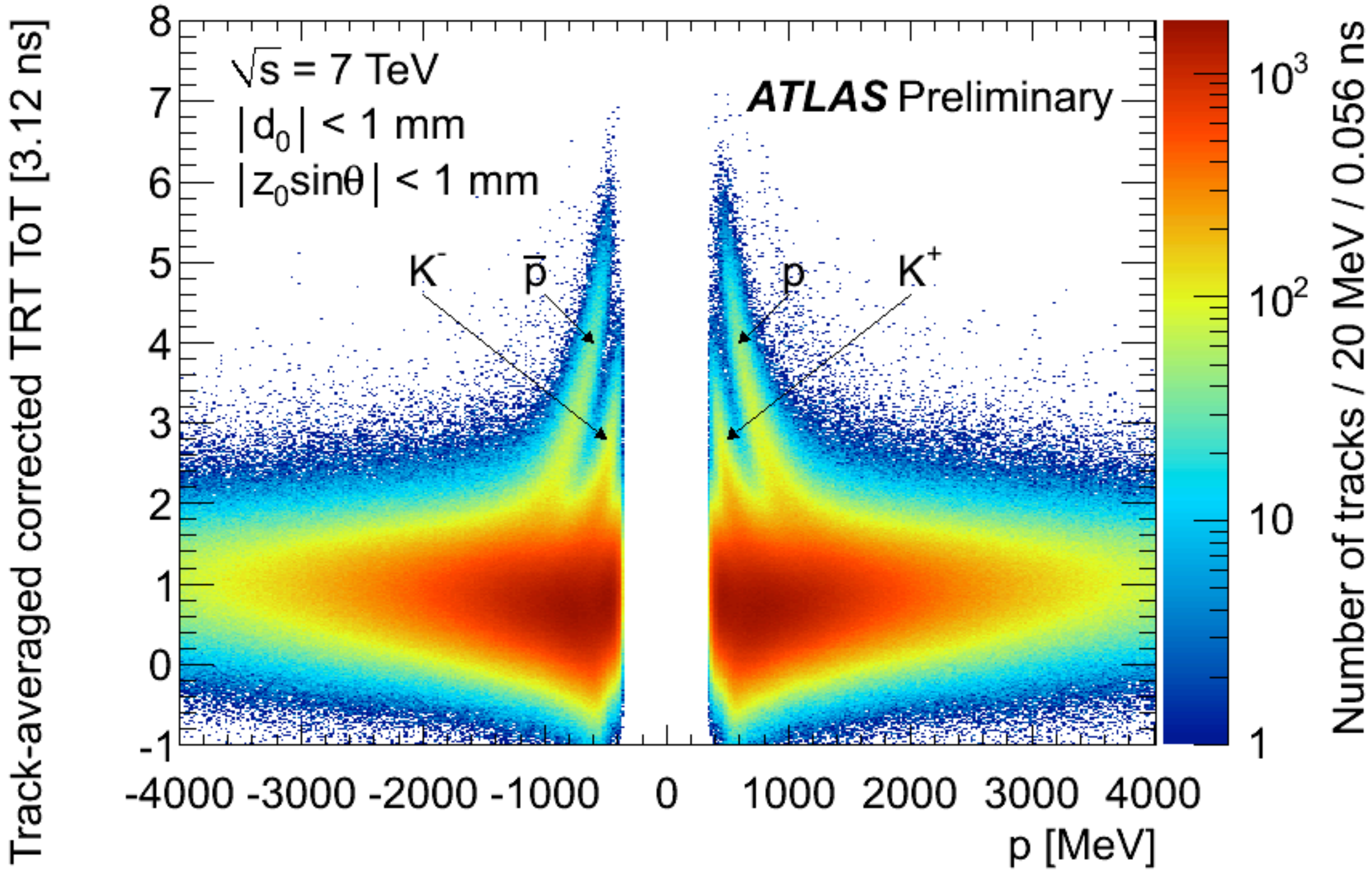
Difficult: services & cooling!





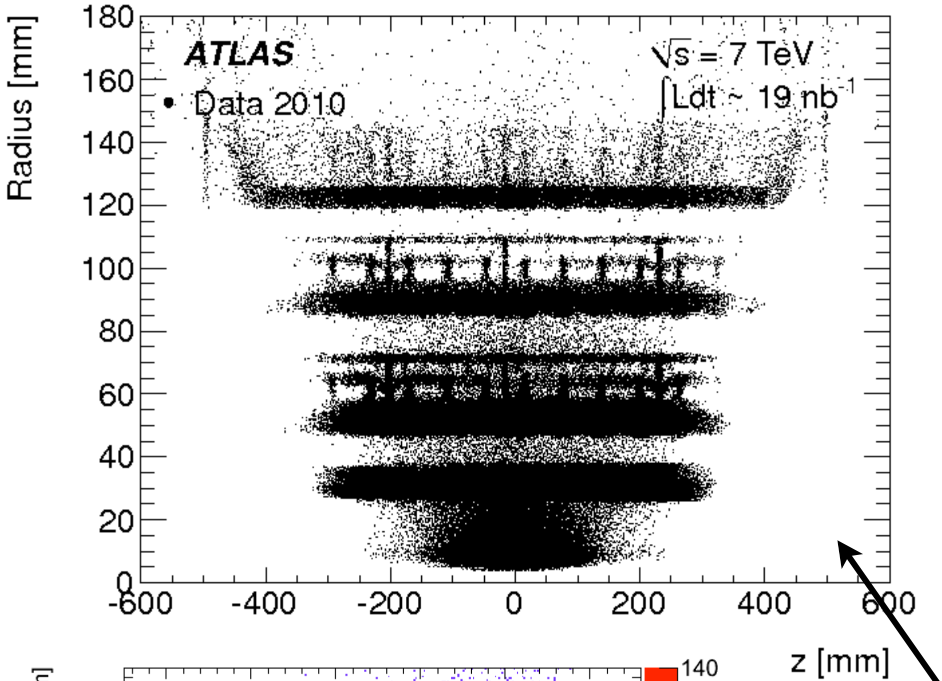
Pixel performance

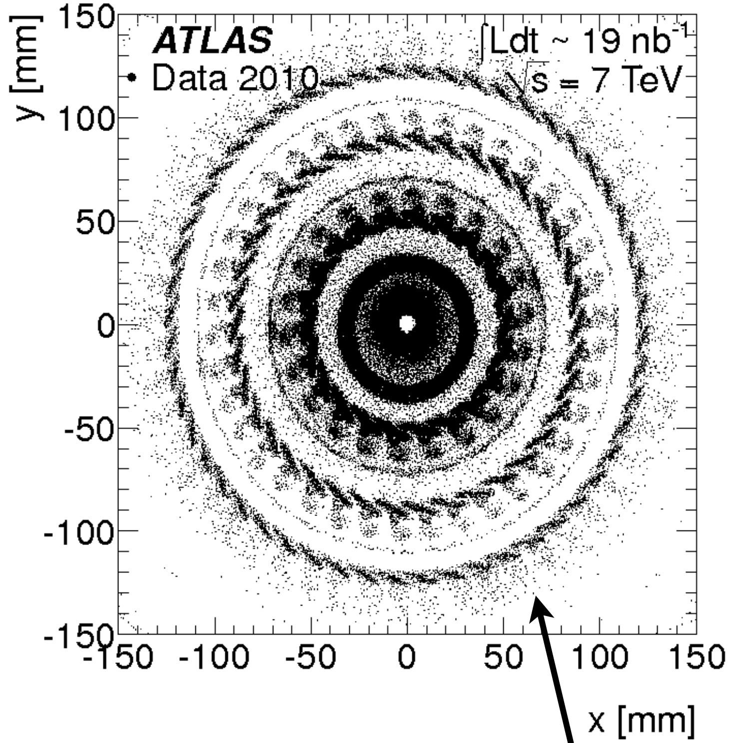
- Typical values for position resolution at the LHC: ~ 9μm
- ...and particle ID measuring energy loss

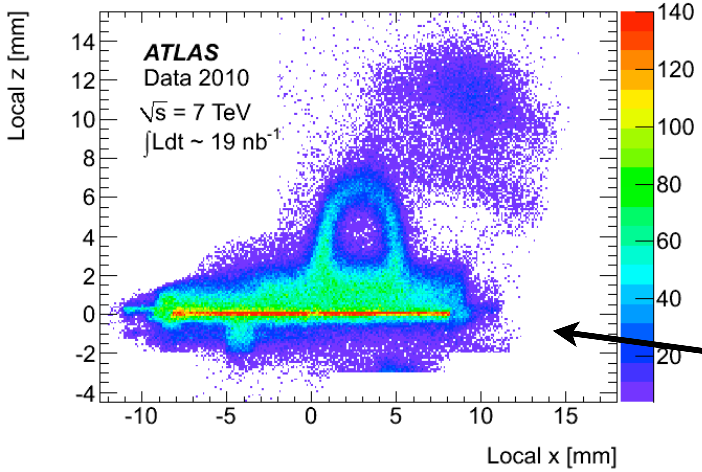


Precise tracking allows material

- E.g. in ATLAS: look for hadronic interactions:







side-view of the ATLAS Pixel region

cross-section of the ATLAS Pixel region

a Pixel module

Apropos material...

- Instead of the comparison CMS - ATLAS and a histogram of the material map of both experiments, I give a link:
  - ➡ **General-Purpose Detectors for the Large Hadron Collider**
    Annual Review of Nuclear and Particle Science
    Vol. 56: 375-440 (Volume publication date November 2006)
    First published online as a Review in Advance on August 2, 2006
    DOI: 10.1146/annurev.nucl.54.070103.181209
    by Daniel Froidevaux and Paris Sphicas

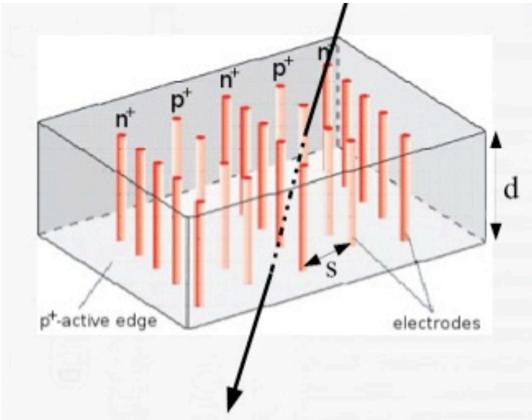
Different approaches for future pixel detectors

Planar Sensor

- current design is an n-in-n planar sensor
- silicon diode
- different designs under study (n-in-n; n-in-p ....)
- radiation hardness proven up to $2.4 \cdot 10^{16}$ p/cm^2
- problem: HV might need to exceed 1000V

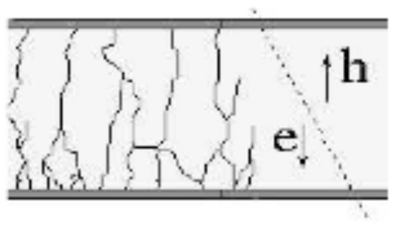
3D Silicon

- Both electrode types are processed inside the detector bulk instead of being implanted on the wafer's surface.
- Max. drift and depletion distance set by electrode spacing



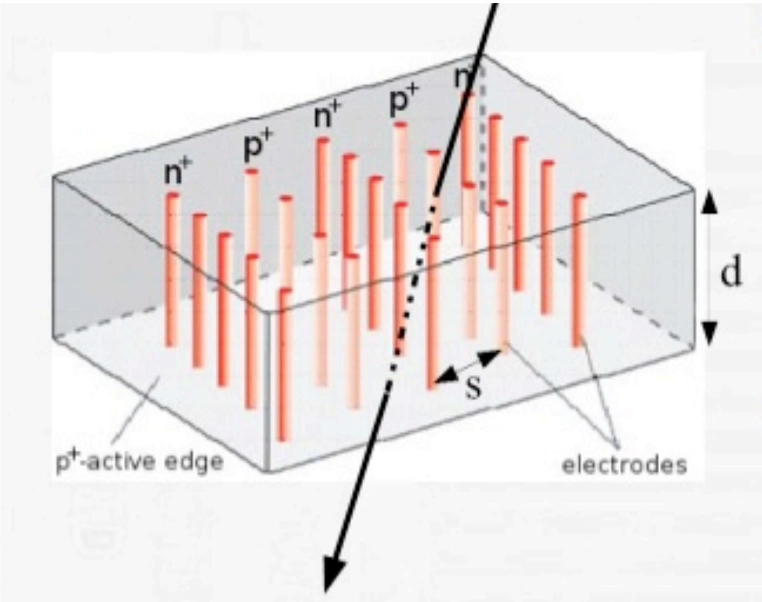
CVD (Diamond)

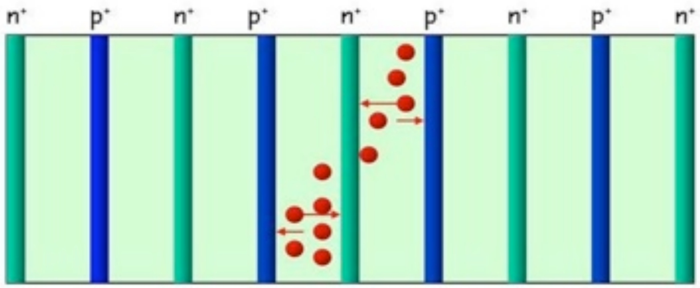
- Poly crystalline and single crystal
- Low leakage current, low noise, low capacitance
- Radiation hard material
- Operation at room temperature possible
- Drawback: 50% signal compared to silicon but better S/N ratio (no dark current)



Choices often “salomonic” ➞ for the ATLAS next generation planar and 3D was chose; for HL-LHC the decision is still open

3D sensors





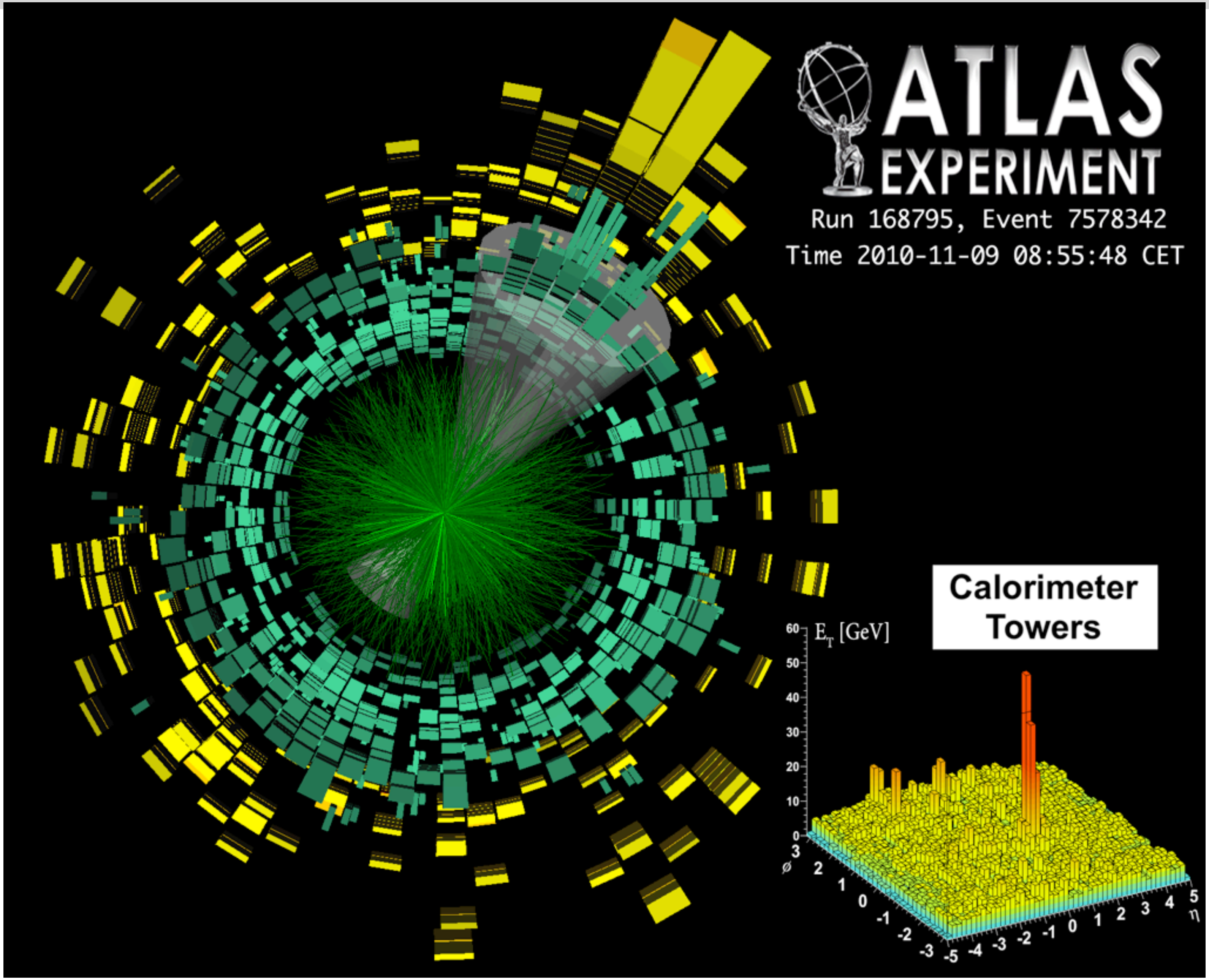
Both electrode types are processed inside the detector bulk instead of being implanted on the wafer's surface.

- 3-d array of p and n electrodes that penetrate into the detector bulk
- Lateral depletion:
  - Max. drift and depletion distance set by electrode spacing
  - Reduced collection time and depletion voltage
  - Thicker detectors possible
  - Low charge sharing

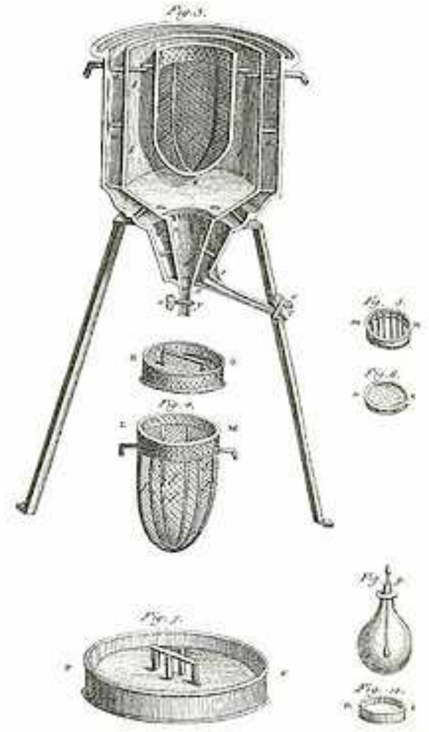
BUT: non-standard (planar) technology

Calorimeters

An event display - Calorimeter



Calorimetry - the idea behind



Historic ice calorimeter 1892

- Calorimetry originated in thermo-dynamics
  - The total energy released within a chemical reaction can be measured by measuring the temperature difference
- In particle physics:
  - Measurement of the energy of a particle by measuring the absorbed energy

N.B. What is the effect of a 1 GeV particle in 1 liter water (at 20°C)?

$\Delta T = E / (c \cdot M_{water}) = 3.8 \cdot 10^{-14}$K !

Calorimetry: Overview

- Basic mechanism for calorimetry in particle physics:
  - formation of electromagnetic
  - or hadronic showers.
- The energy is converted into ionisation or excitation of the matter.

Charge

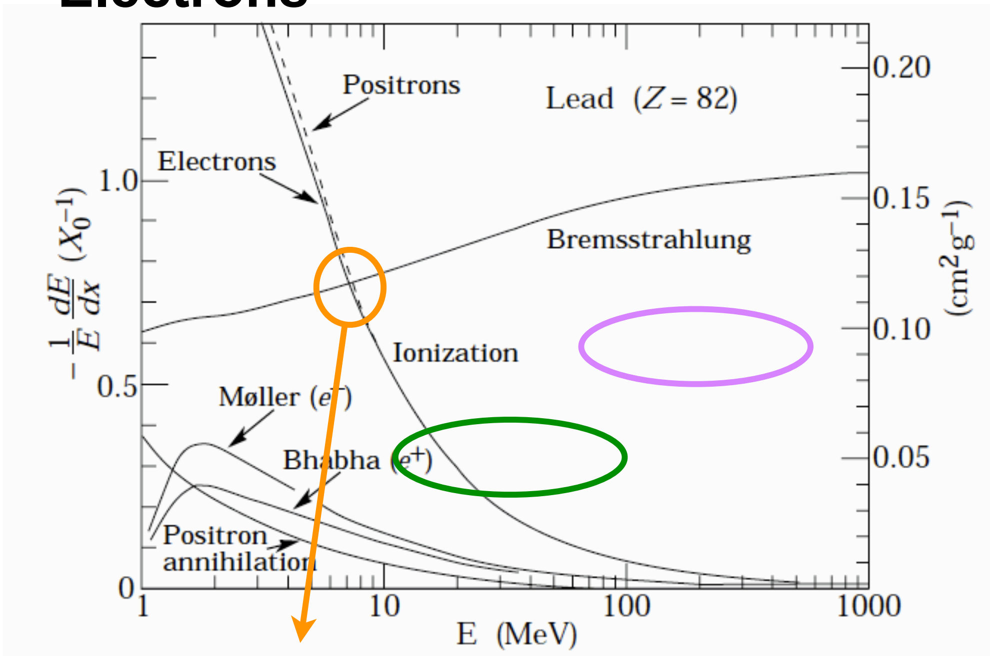
Scintillation light

Cherenkov light

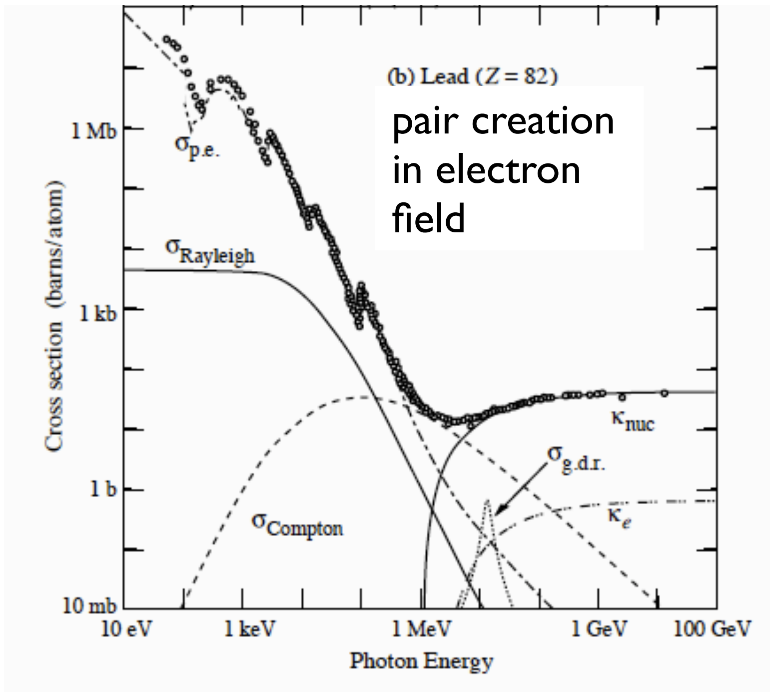
- Calorimetry is a "destructive" method. The energy and the particle get absorbed!
- Detector response $\propto E$
- Calorimetry works both for charged (e± and hadrons) and neutral particles (n,γ) !

Reminder

Electrons



Photons



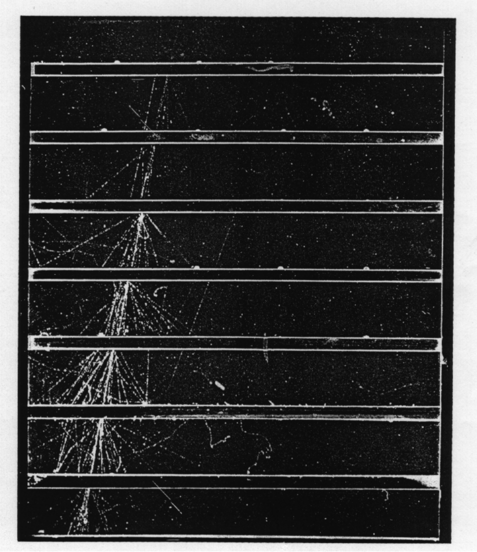
- **Critical energy:** the energy at which the losses due to ionisation and Bremsstrahlung are equal

- **Radiation length** defines the amount of material a particle has to travel through until the energy of an electron is reduced by Bremsstrahlung to 1/e of its original energy $\langle E_e(x) \rangle \propto e^{\frac{x}{X_0}}$

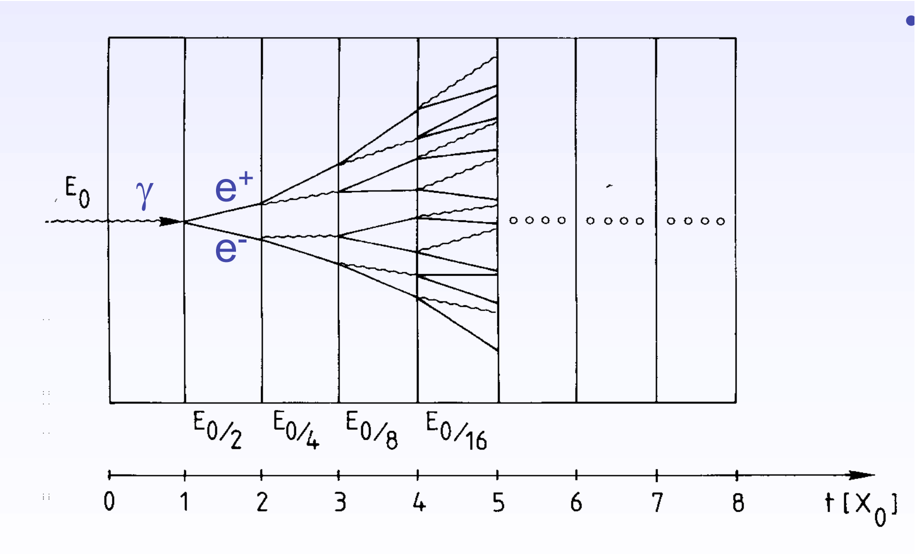
empirical: $$X_0 = \frac{716.4\,A}{Z(1+Z)\,ln(287/\sqrt{Z})}\,\frac{g}{cm^2} \propto \frac{A}{Z^2}$$

• Electromagnetic showers

- High energetic particles are forming a shower if passing through (enough) matter.
- An alternating sequence of interactions leads to a cascade:
  - Primary γ with E_0 energy pair-produces with 54% probability in layer X_0 thick
  - On average, each has $E_0/2$ energy
  - If $E_0/2 > E_c$, they lose energy by Bremsstrahlung



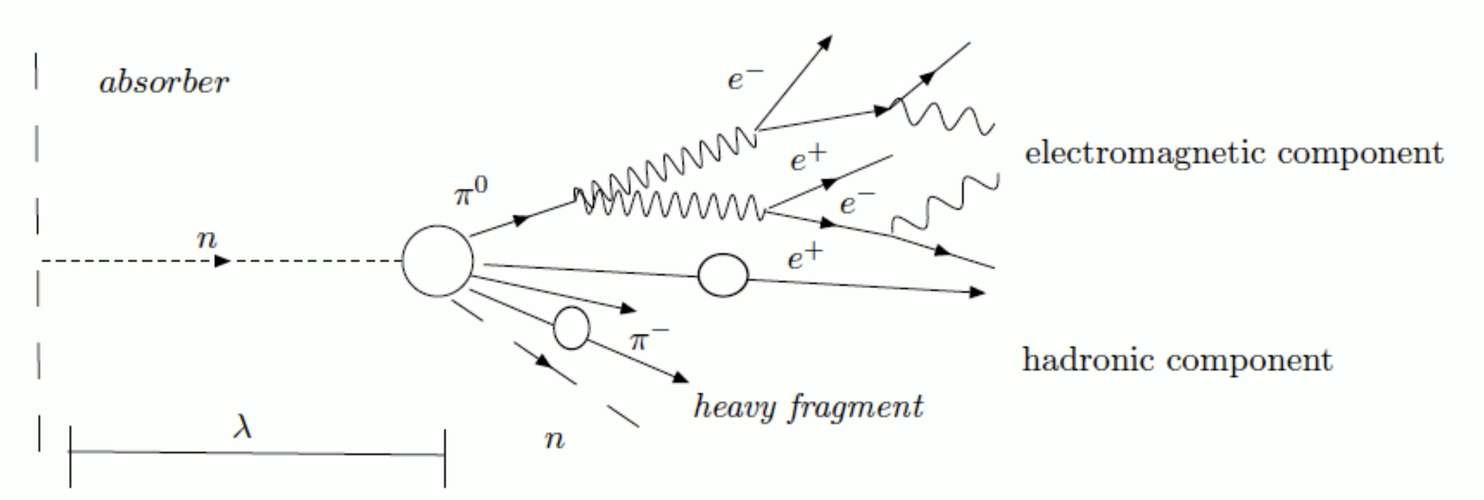
Cloud chamber photo of electromagnetic cascade between spaced lead plates.



- Next layer X_0, charged particle energy decreases to $E_0/(2e)$
- Bremsstrahlung with an average energy between $E_0/(2e)$ and $E_0/2$ is radiated
- Radiated γs produce again pairs

Hadronic cascades

- Within the calorimeter material a hadronic cascade is build up: in inelastic nuclear processes more hadrons are created



The length scale of the shower is given in means of the nuclear reaction length λ_I

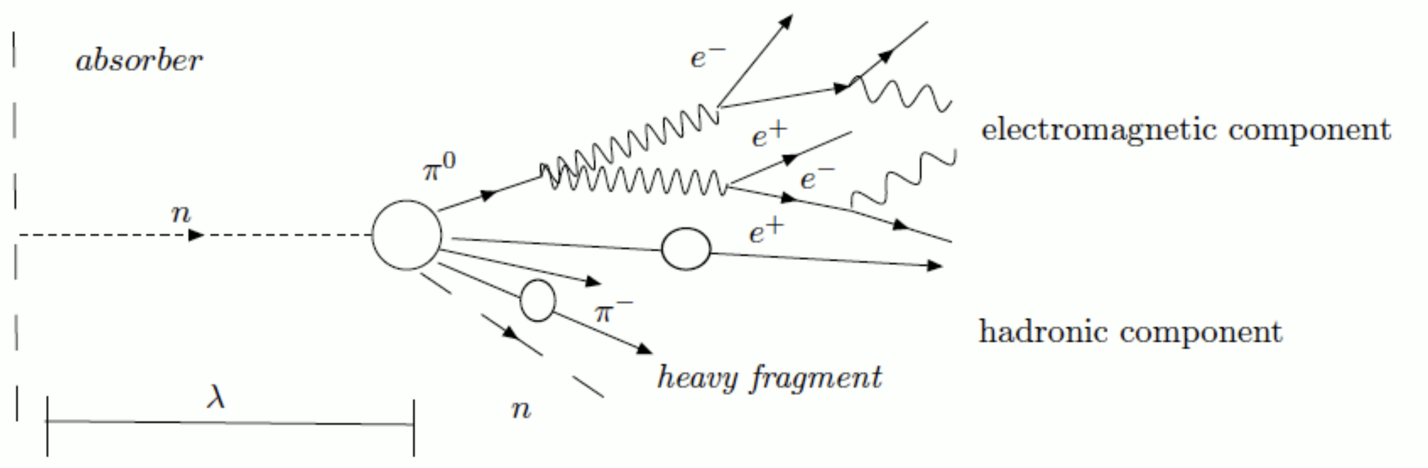
$$\lambda_l = \frac{A}{N_A \sigma_{total}}$$

total cross section for nuclear processes

	λ_I	X_0
Polystyren	81.7 cm	43.8 cm
PbWO	20.2 cm	0.9 cm
Fe	16.7 cm	1.8 cm
W	9.9 cm	0.35 cm

Compare X_0 for high-Z materials, we see that the size needed for hadron calorimeters is large compared to EM calorimeters.

Hadronic cascade: details



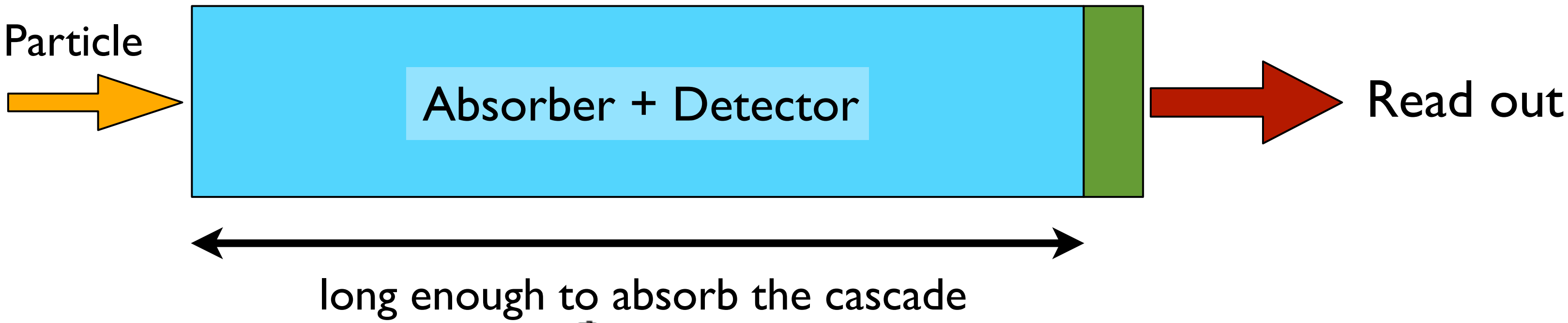
- Hadronic showers are way more complicated than em showers:
    - high energetic secondary hadrons taking a significant part of the momentum of the primary particle [e.g. O(GeV)]
    - a significant part of the total energy is transferred into nuclear processes: nuclear excitation, spallation, ... ➠ Particles in the MeV range
    - Special case: Neutral pions (1/3 of all pions), decay instantaneously into two photons ➠ start of an em shower

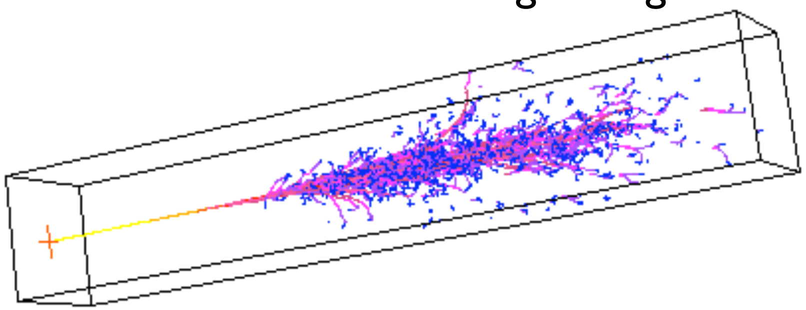
Calorimeter types (I)

Two different types of calorimeters are commonly used: **Homogeneous** and **Sampling Calorimeters**

Homogeneous Calorimeters:

- Absorber material is active; the overall deposited energy is converted into a detector signal
- Pro: very good energy resolution
- Contra: Segmentation difficult, selection of material is limited, difficult to built compact calorimeters

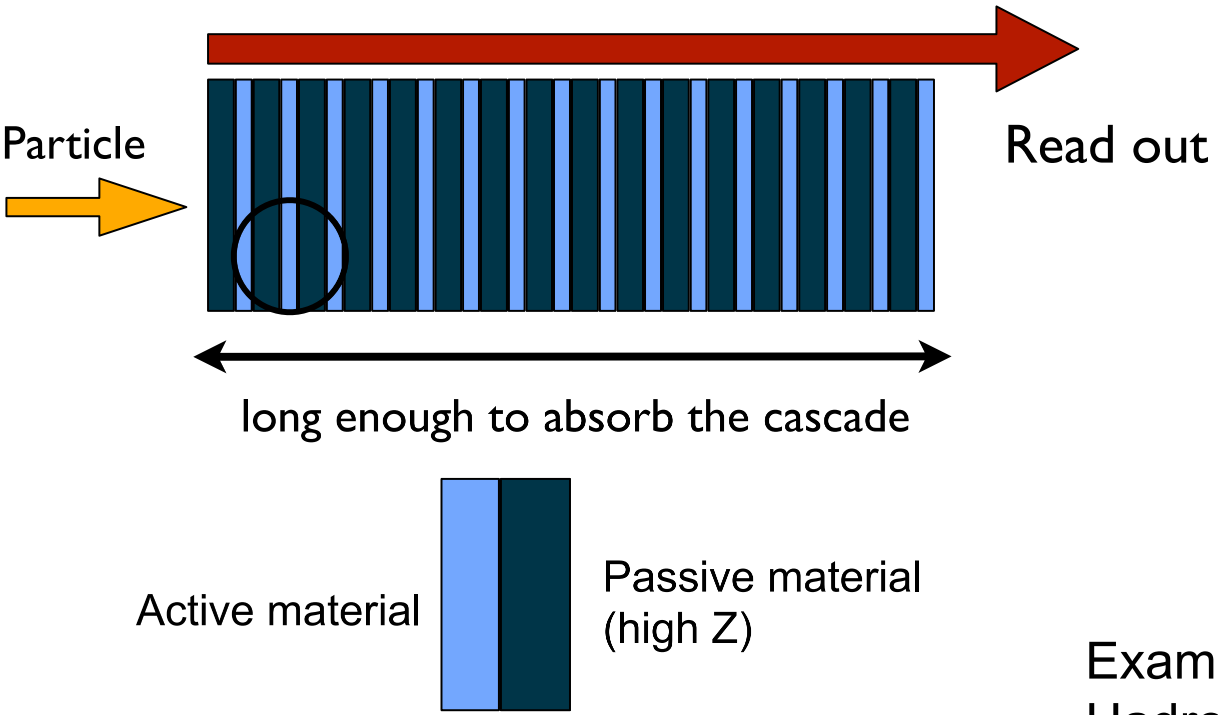




Example: Crystal calorimeter as for CMS ECAL (PbWO4 crystals)

Sampling Calorimeters

- **Sampling Calorimeter**
  - Layer structure of passive material and active detector material; only a fraction of the deposited energy is "registered"
  - Pro: Segmentation (transversal and lateral), compact detectors by the usage of dense materials (tungsten, uranium,…)
  - Contra: Energy resolution is limited by fluctuations



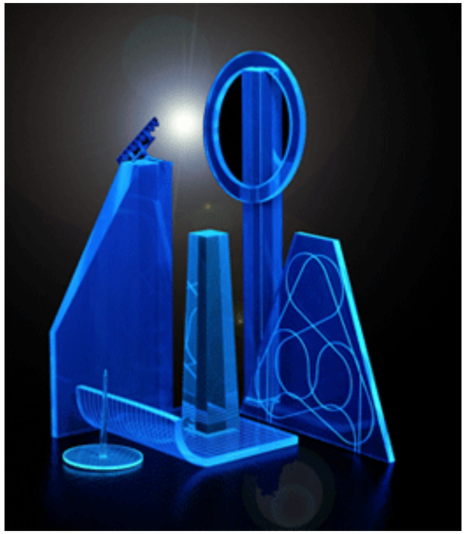
Important parameter:
Sampling Fraction

The fraction of the energy of a passing particle seen by the active material.

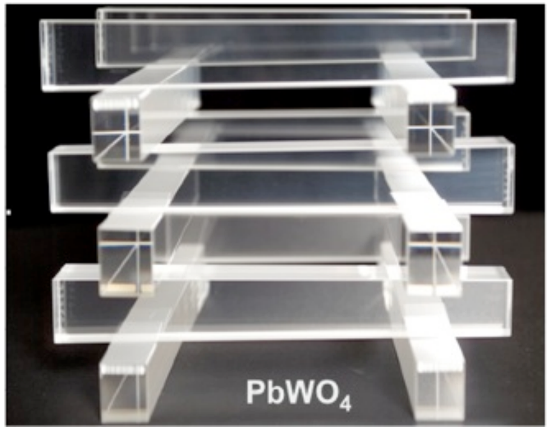
Typically in the procent range

Example: ZEUS Uranium Calorimeter, Hadronic Calorimeters LHC

An important part of many calorimeters: scintillators



- Detectors based on Registration of excited atoms
- Emission of photons by excited atoms, typically UV to visible light.
  - Observed in Noble Gases (even liquid !)
  - Oter materials: Polyzyclic Hydrocarbons (Naphtalen, Anthrazen, organic Scintillators). Large scale industrial production, mechanically and chemically quite robust.
  - Inorganic Crystals are substances with largest light yield. Used for precision measurement of energetic photons, used e.g. in nuclear medicine.

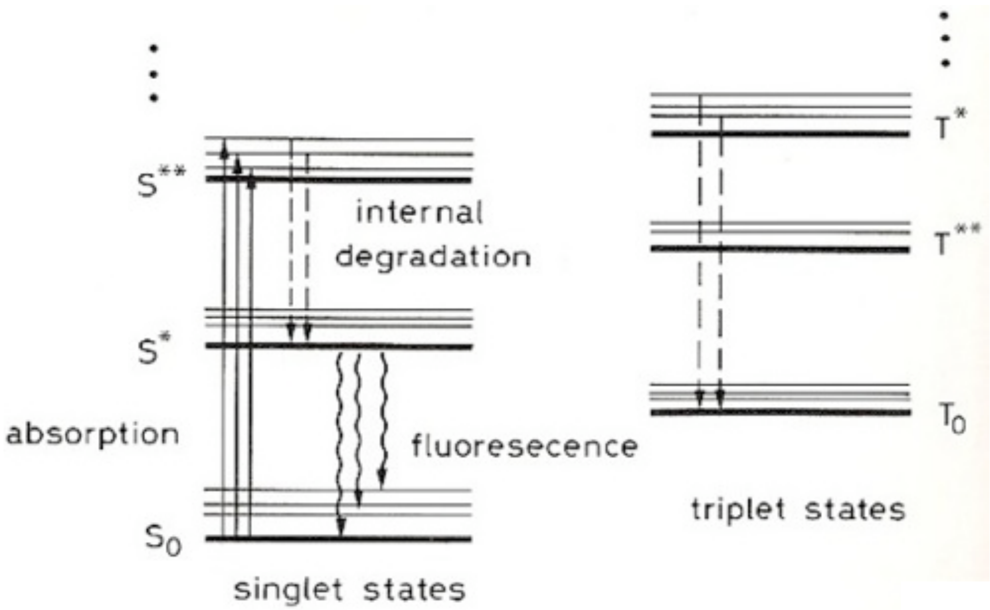


- $PbWO_4$: Fast, dense scintillator,
  - Density ~ 8.3 g/cm^3 (!)
  - ρ_M 2.2 cm, X_0 0.89 cm
  - low light yield: ~ 100 photons / MeV

16

Scintillators to measure the deposited energy

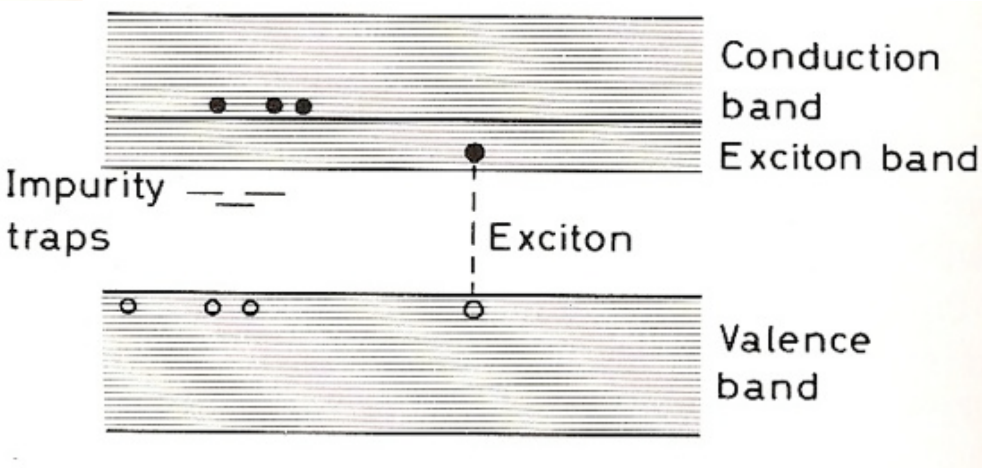
- Very common: Measurement of the deposited energy using scintillation



- Scintillators emit light when ionising particles pass the material
- Excitation of meta stabel states in molecules (organic Scint.) or “Störstellen” in crystals (anorganic)

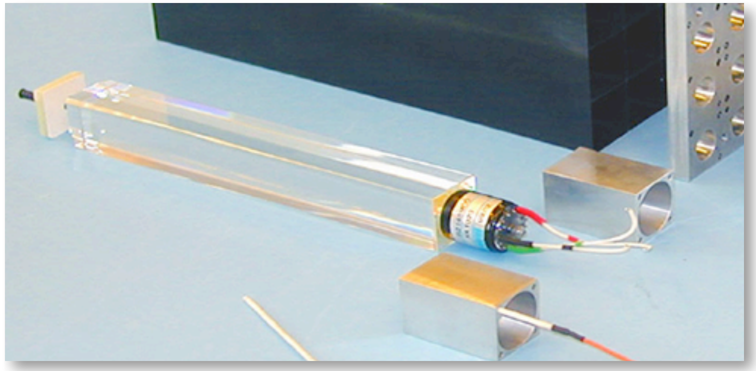
Scintillator spin-off:
a matter of taste...

anorganic:

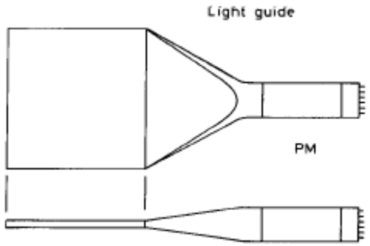


Light transport

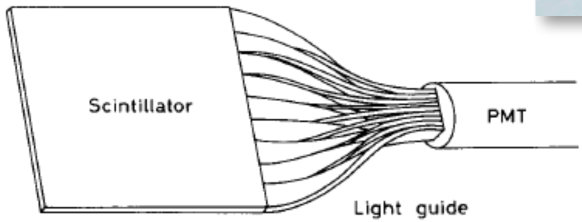
- The photons are being reflected towards the end of the scintillator
- A light guide brings the light to a Photomultiplier



- Light guides: transfer by total internal reflection (+outer reflector)

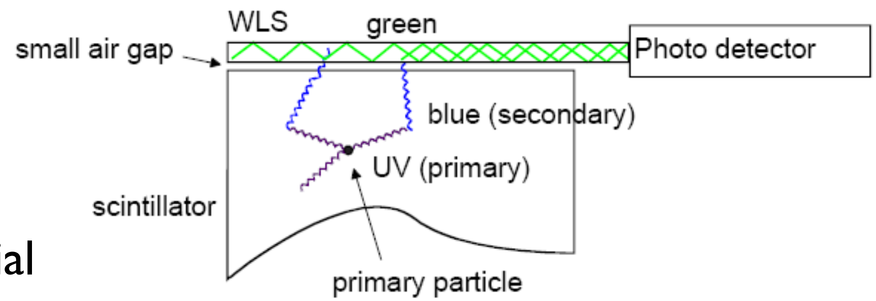


"fish tail"



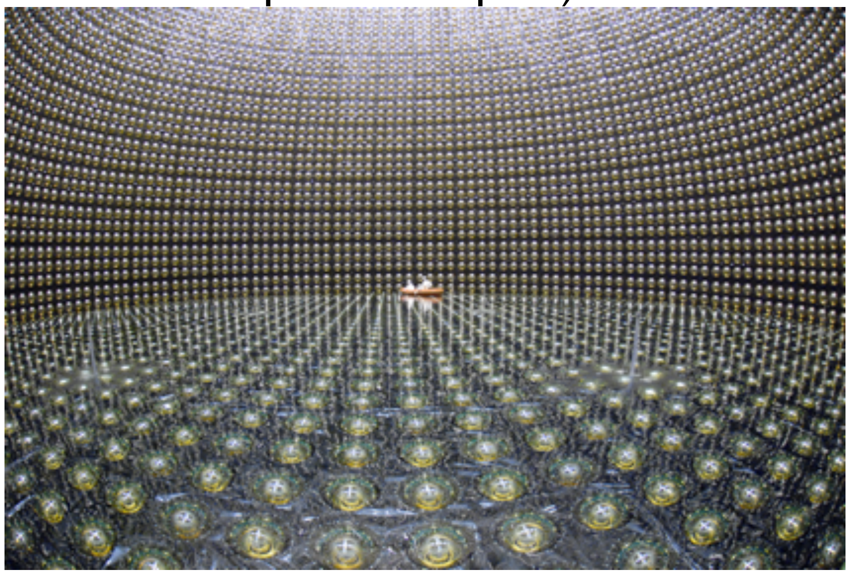
adiabatic

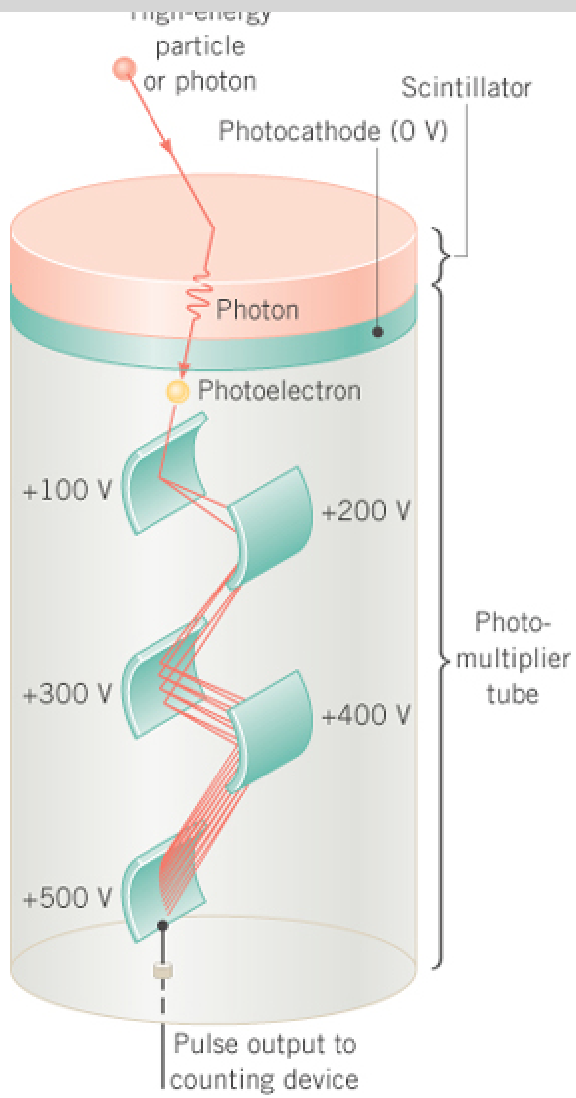
- UV light enters the WLS material
- Light is transformed into longer wavelength
- -> Total internal reflection inside the WLS material
- -> 'transport' of the light to the photo detector



Detection of photons: photomultiplier

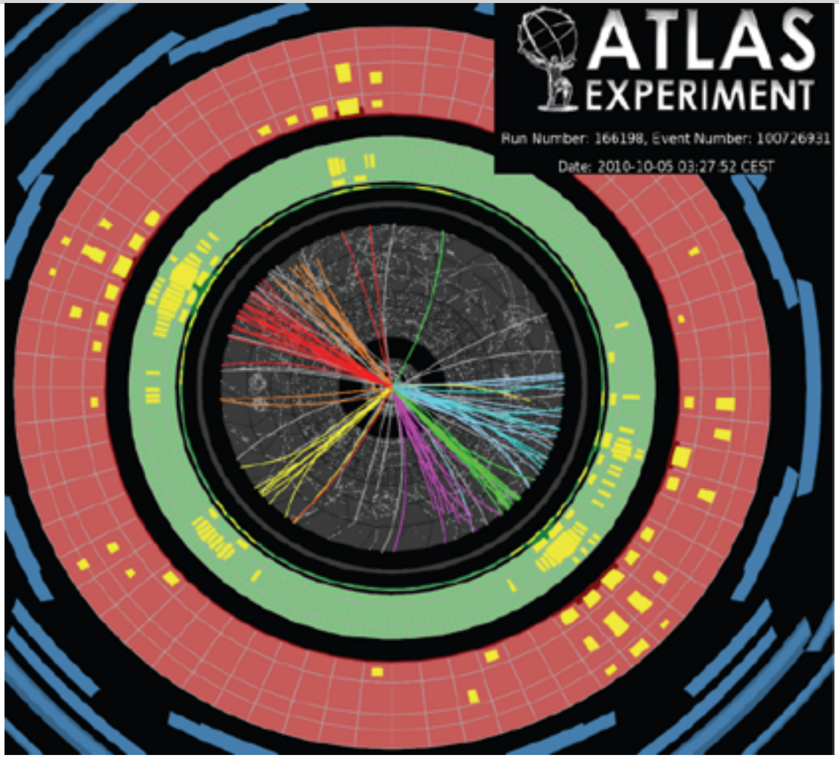
- **The classic method** to detect photons
  - Conversion of a photon into electrons via photo-electric effect when the photon impinges on the photo cathode
  - The following dynode system is used to amplify the electron signal
  - Usable for a large range of wave lengths (UV to IR)
  - good efficiencies, single photon detection possible
  - large active area possible (SuperKamiokande - 32000 tons of water and 11200 photomultiplier)

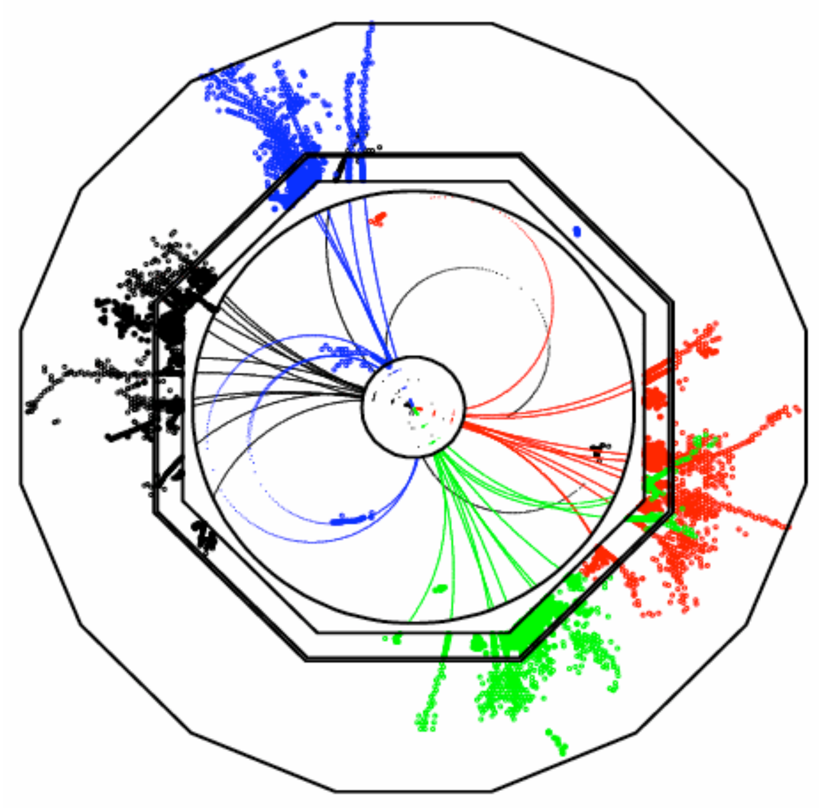




Source: Cutnell and Johnson, 7th edition image gallery

Present hadron calorimeters... and DREAMS



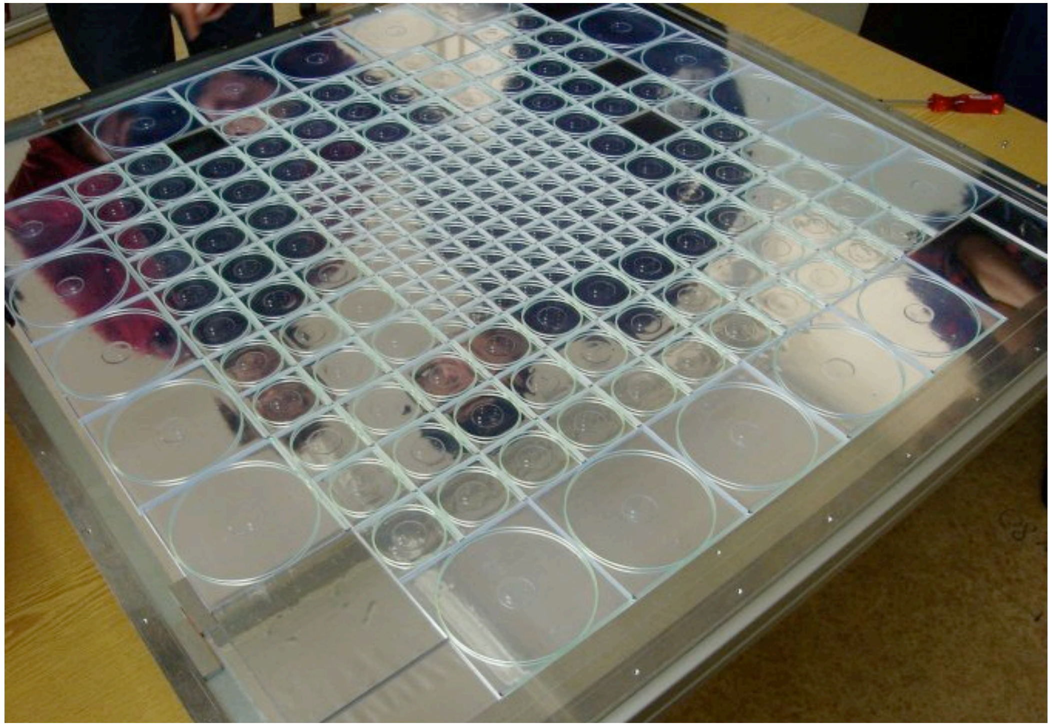


- Tower-wise readout: light from many layers of plastic scintillators is collected in one photon detector (typically PMT) O(10k) channels for full detectors

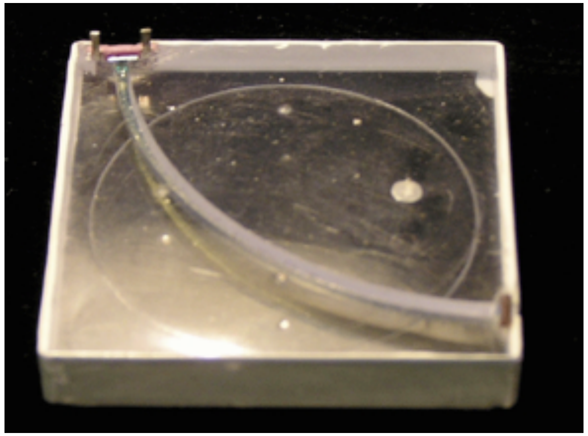
- Extreme granularity to see shower substructure: small detector cells with individual readout for Particle Flow O(10M) channels for full detectors

New concepts: highly granular calorimeters

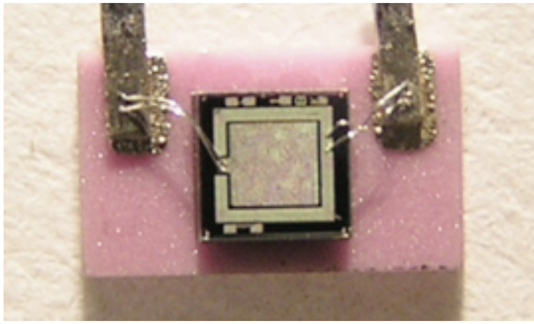
- CALICE (CAlorimeter for a LInear Collider Experiment) HCAL prototype:
  - highly granular readout: 3 x 3 cm^2 scintillator tiles, 38 layers (~4.7 λ_{int}), each tile with individual SiPM readout



tiles in one layer

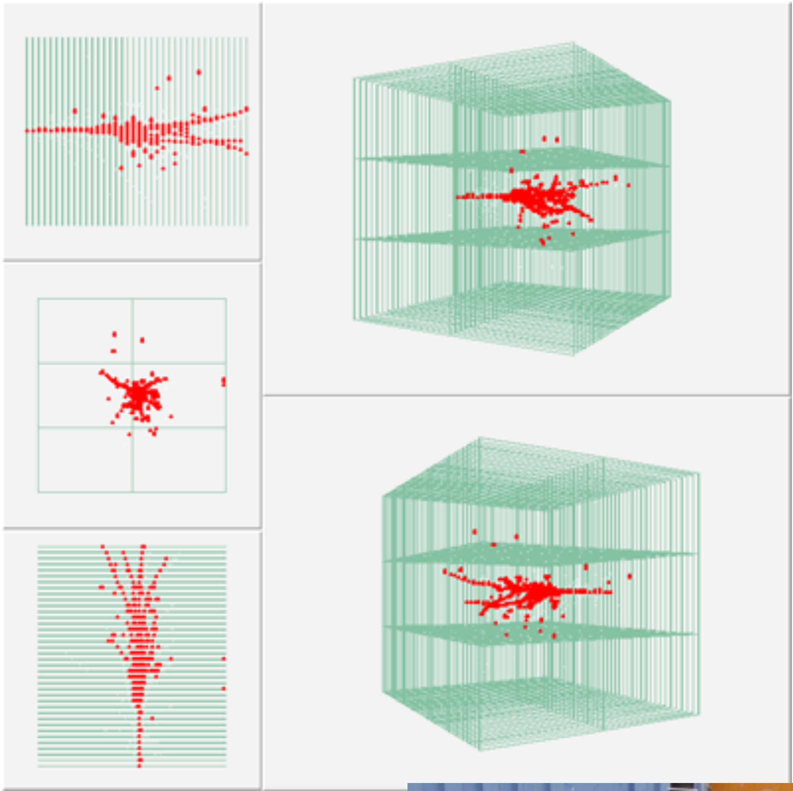


Scintillator tile with WLS fibre

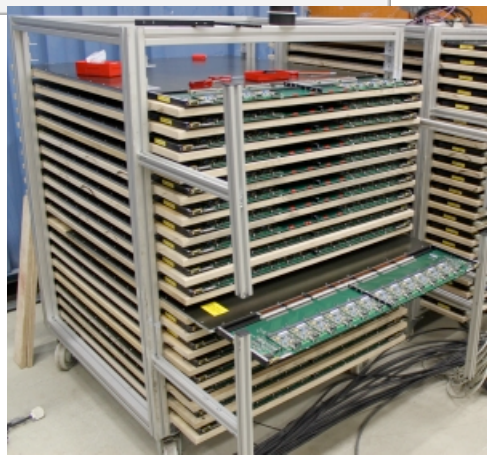


Silicon photo-multiplier

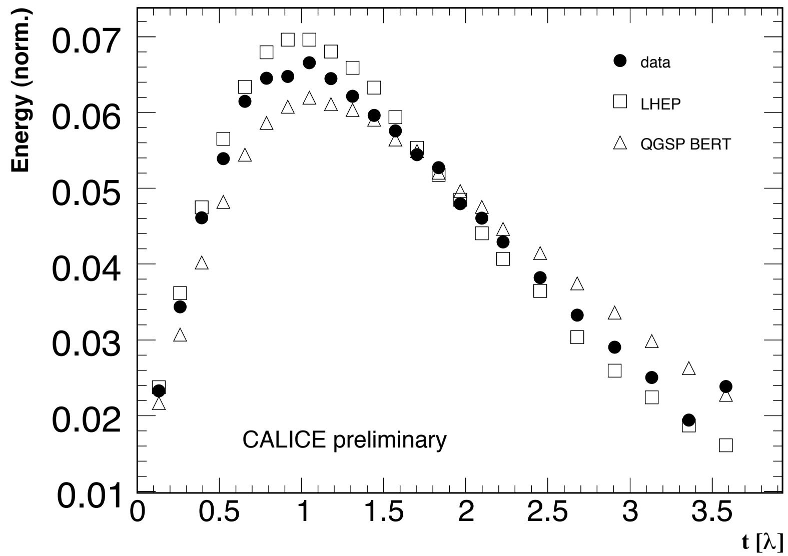
CALICE: detailed studies of hadronic showers



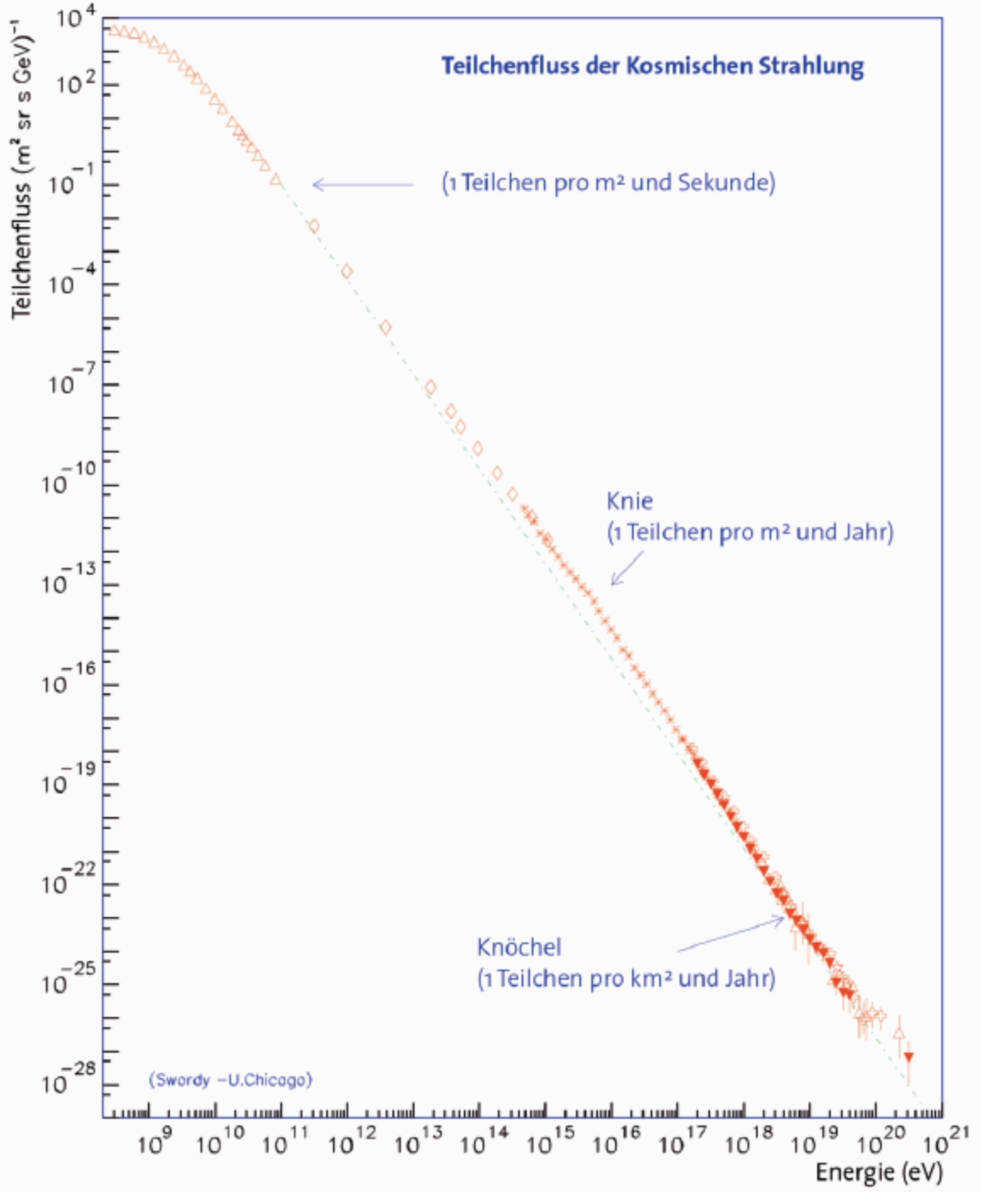
Beam
25 GeV π^-



- Highly granular calorimeters allows better understanding of showers, e.g. comparison of detailed test beam studies with simulations: improvement of existing shower models



Calorimeters are used everywhere!!!

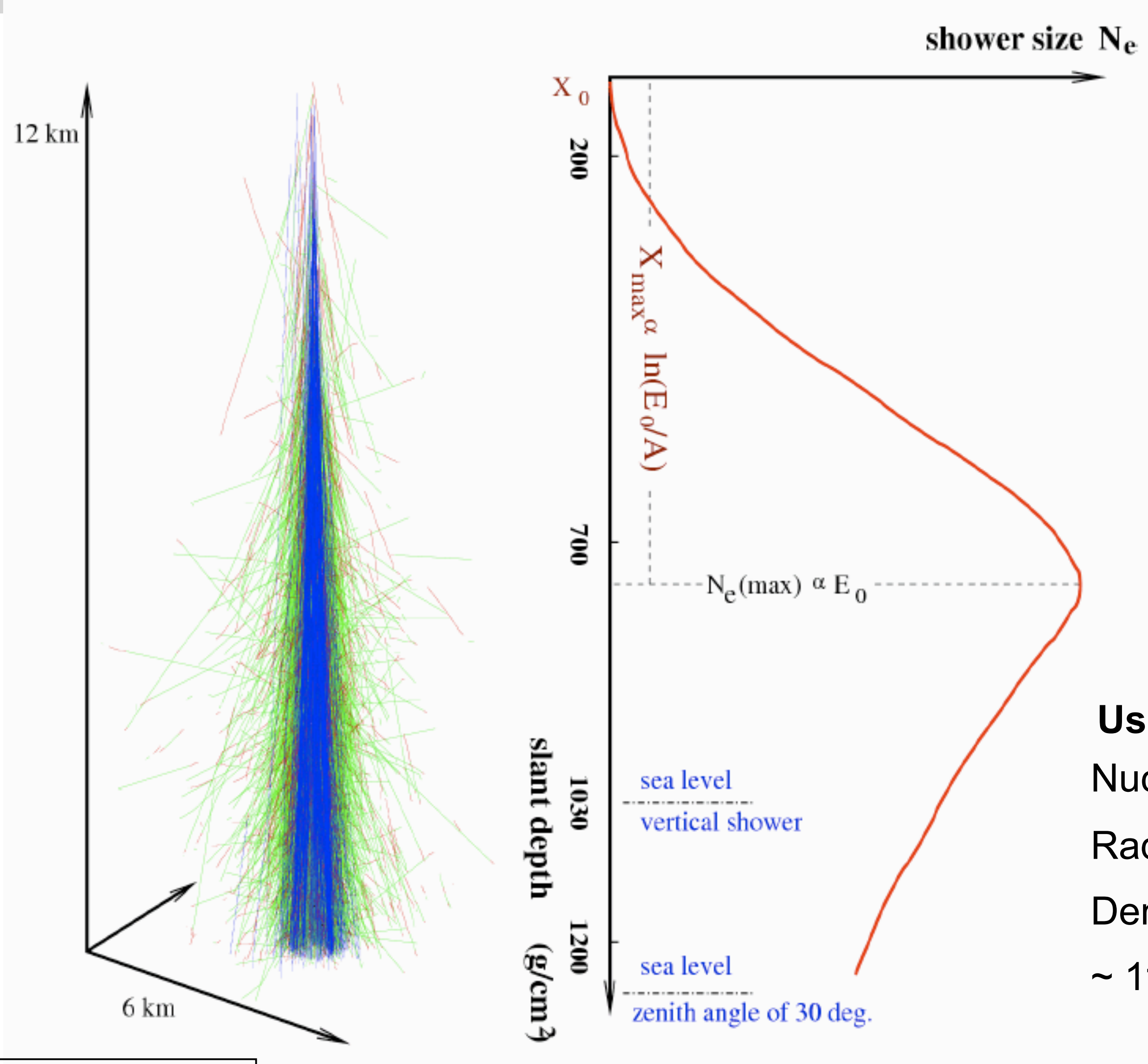


- The methods used in particle physics are more and more used in astroparticle physics.

Requirements are different

- Search for extremely rare reactions
  - Large areas and volumes have to be covered
  - Background needs to be well suppressed
  - High efficiency: no event can be lost!
  - Data rate, radiation damage etc. are less of a problem

Air showers



R.Engel, ISAPP2005

- Mainly electromagnetic: photons, electrons
- Shower maximum: $\sim \ln(E_0/A)$

Use atmosphere as calorimeter

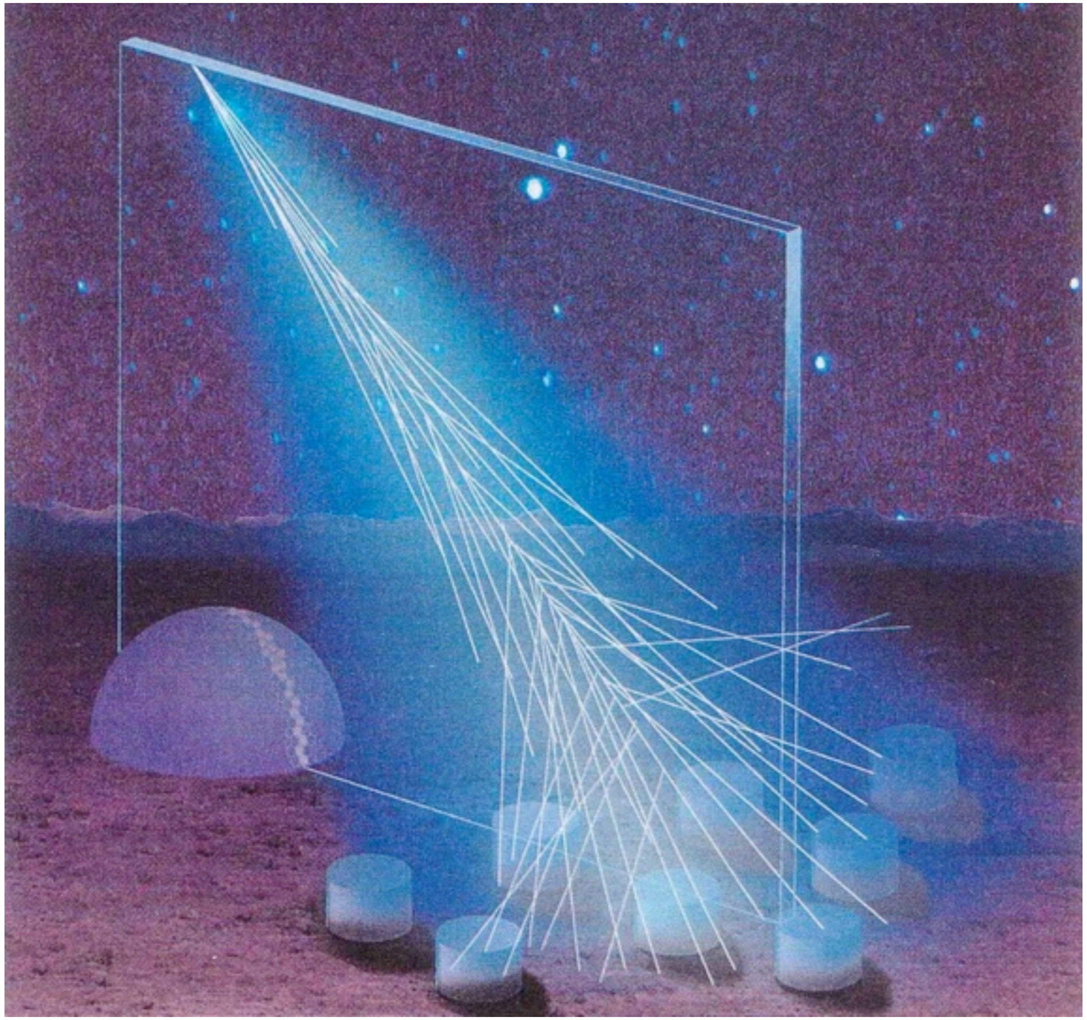
Nuclear reaction length $\lambda_I \sim 90$ g/cm^2

Radiation length $X_0 \sim 36.6$ g/cm^2

Density: ~ 1035 g/cm^2

$\sim 11\ \lambda_I$, $\sim 28\ X_0$

Two techniques



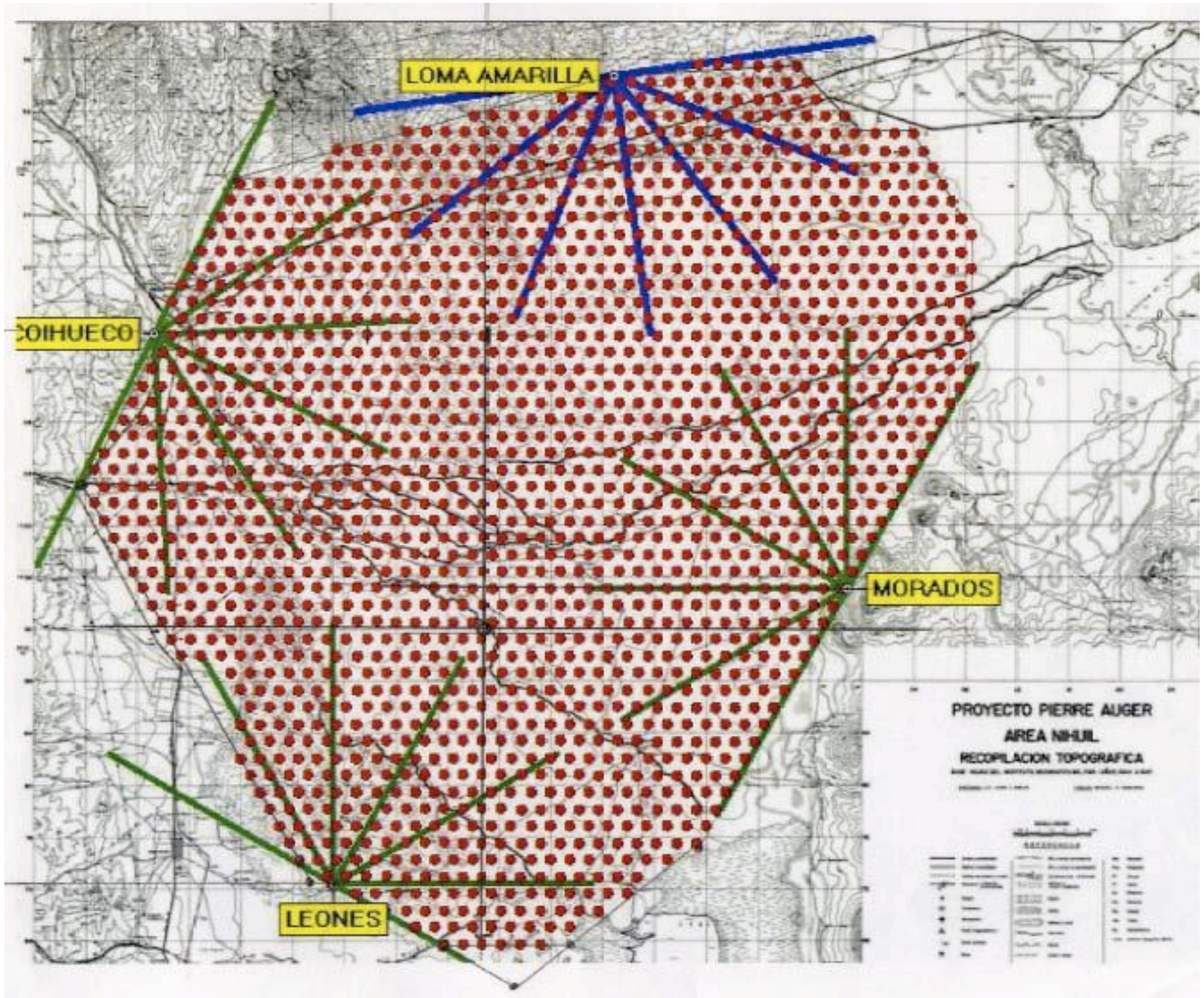
- The atmosphere as homogeneous calorimeter:
  - Energy measurement by measuring the fluorescence light

This is only possible with clear skies and darkness !

- A one-layer sampling calorimeter 11 λ absorber
  - Energy measurement using particle multiplicity

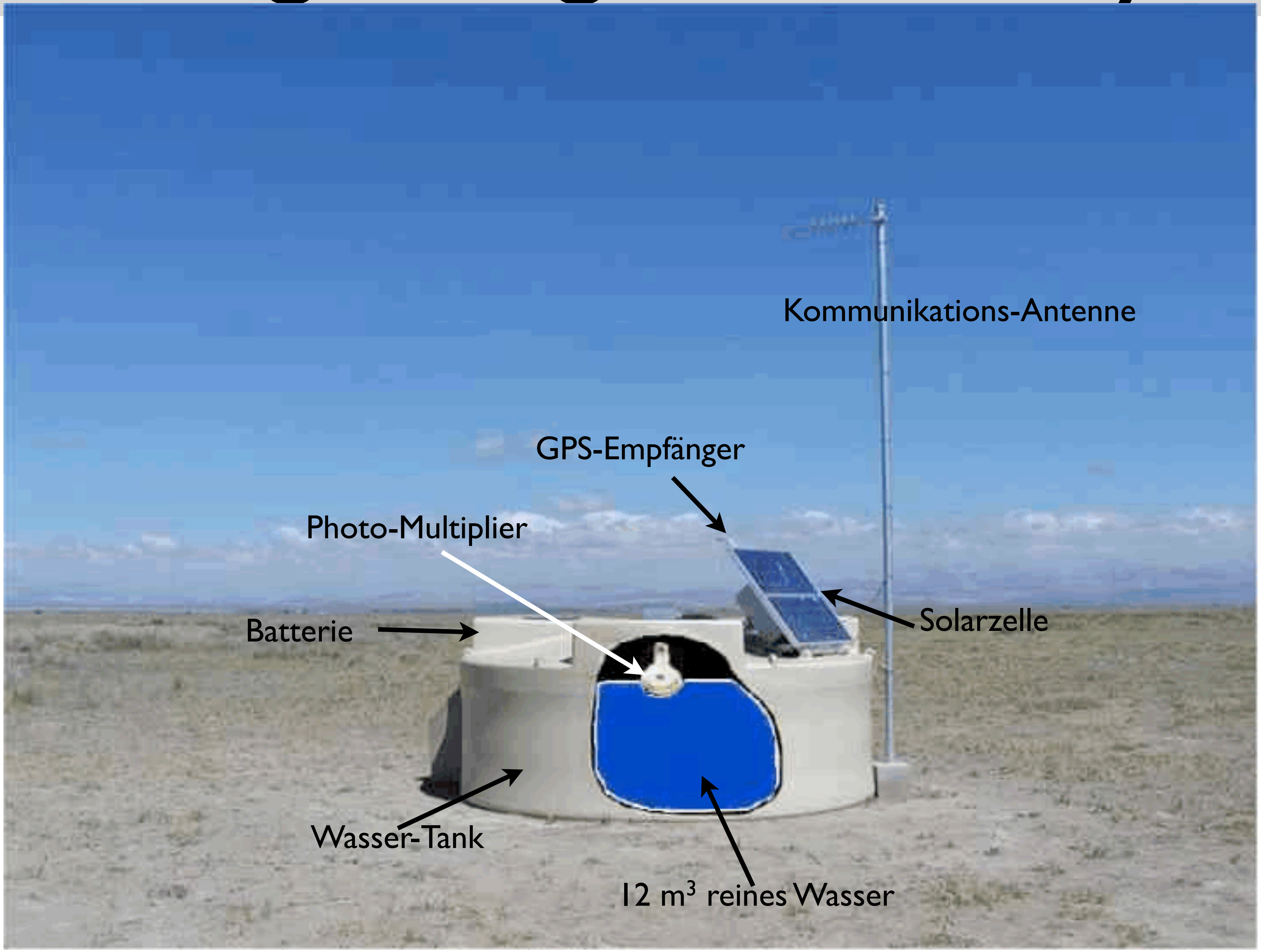
Always possible but has large uncertainties !

Auger-South: Argentinian Pampa



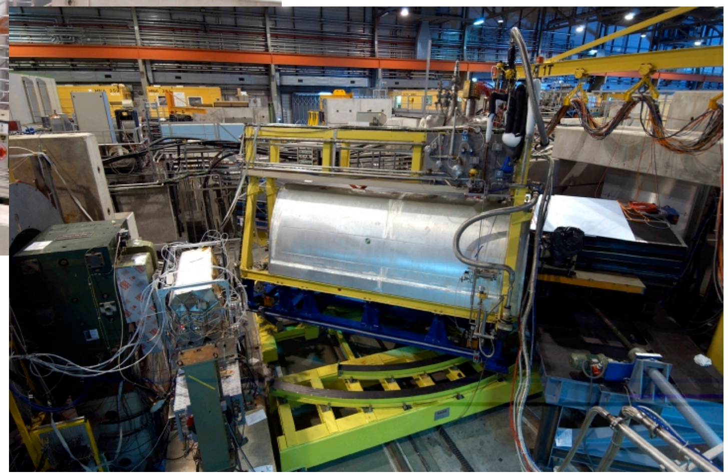
- 1600 water-Cherenkov detectors on ground
- 4 Flourorescence-stations with 6 telescopes
- Covered area:
  3000 km^2 (10 x München)
- Designed to measure energies above 10^{18}eV

Auger: a ground array

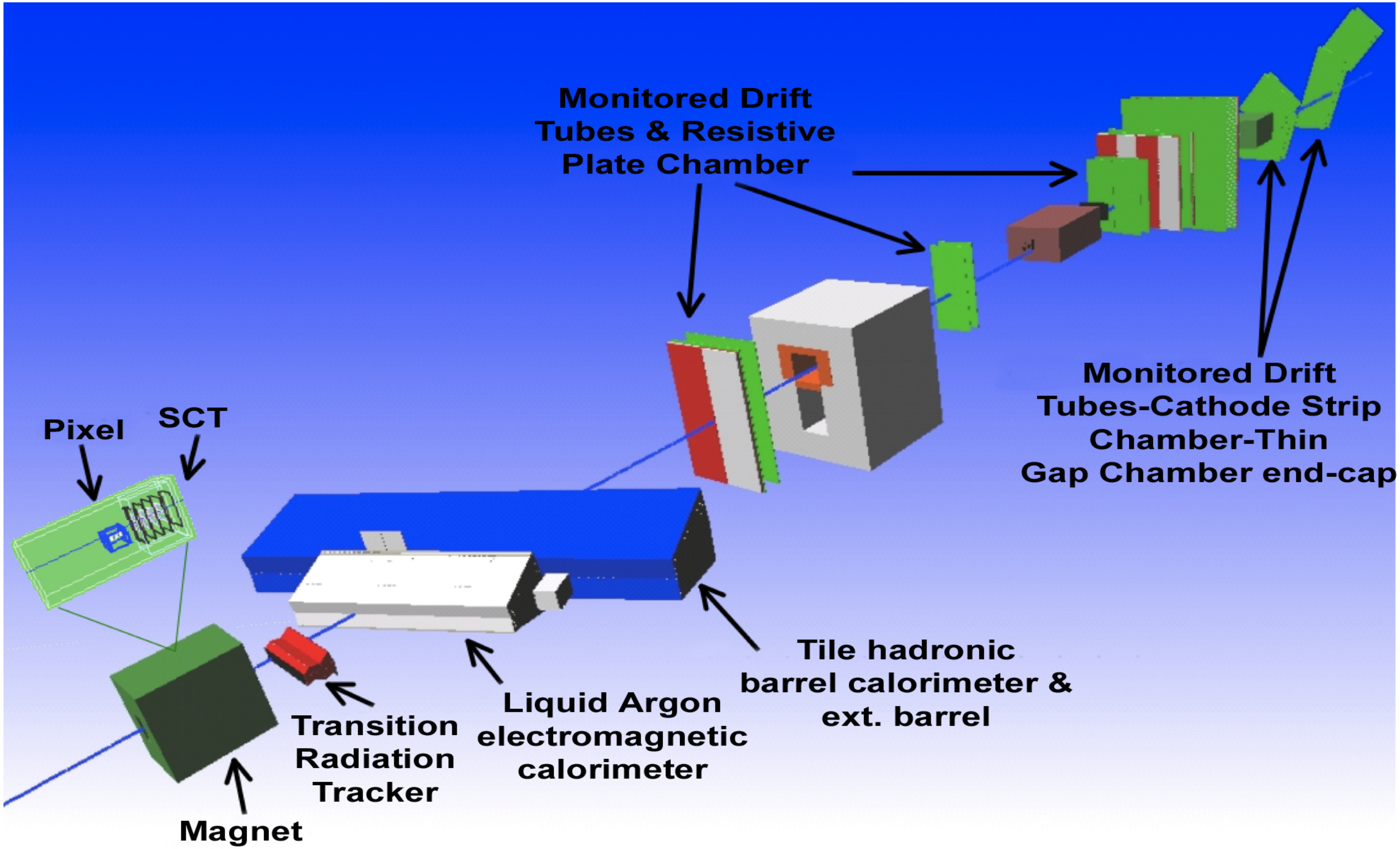


A word on test beams

- “Life is a test beam” (unknown detector physicist)
- Huge facilities and test beam areas at CERNs PS and SPS

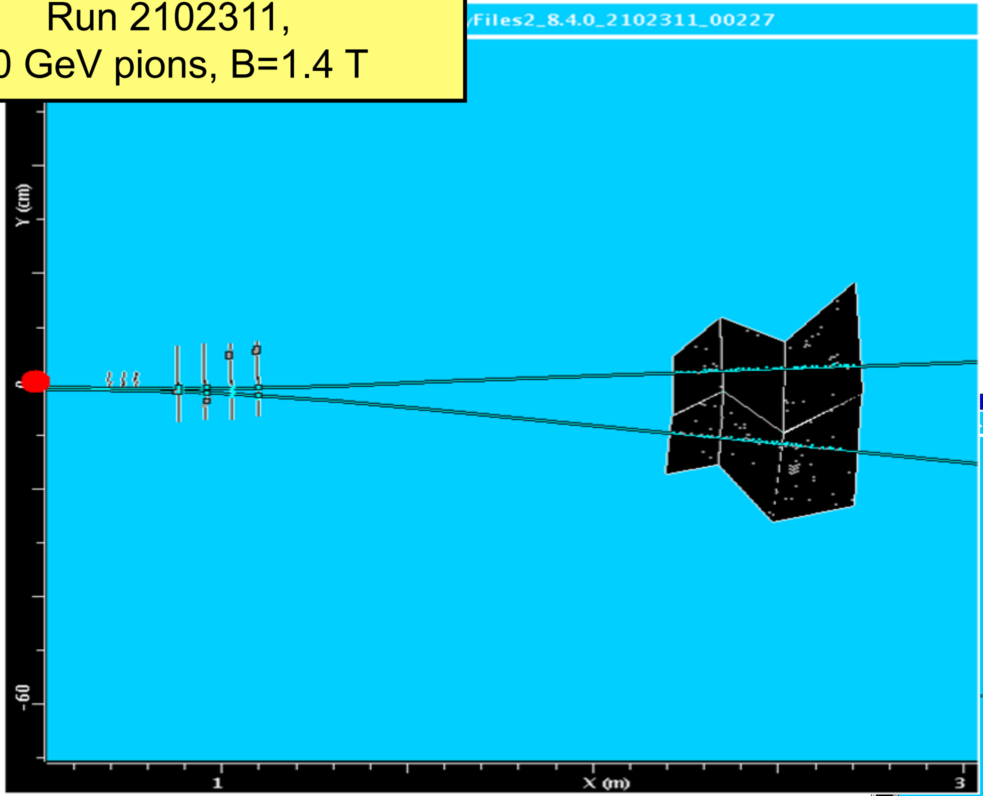


2004: ATLAS combined test

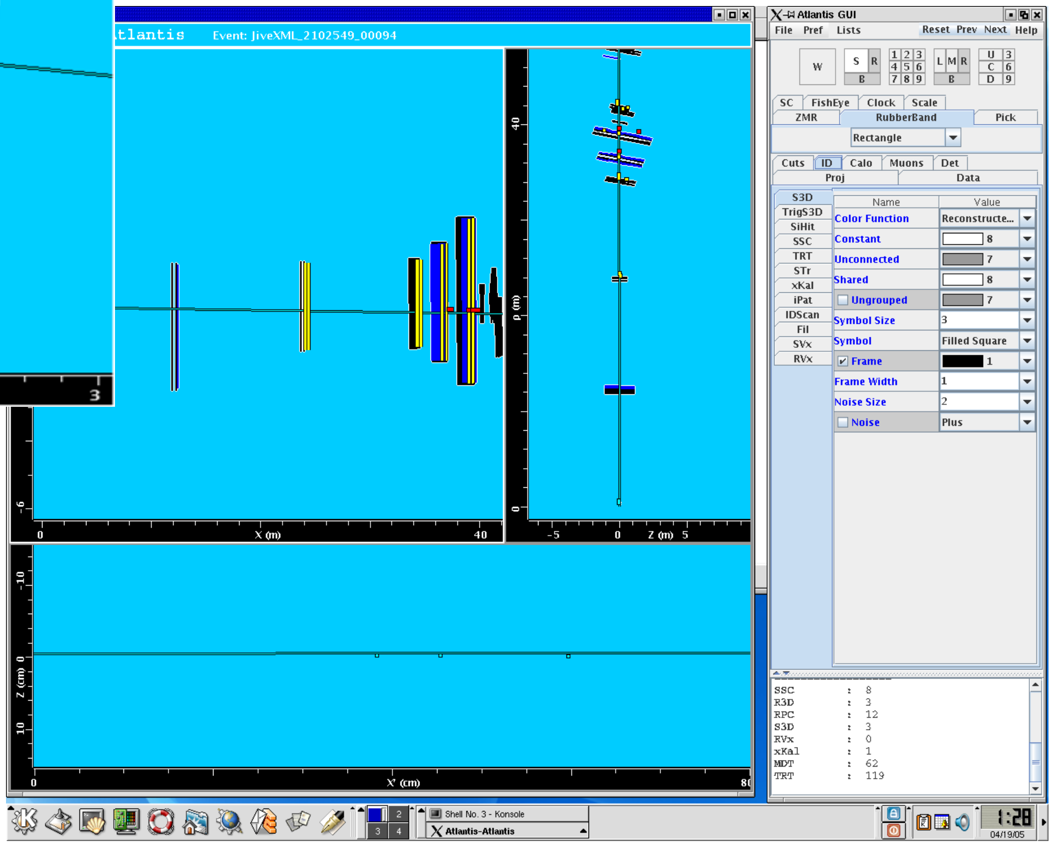


Tracks through the tracker up to the muon chambers

Run 2102311,
20 GeV pions, B=1.4 T



Run 2102549,
180 GeV muons, B=0

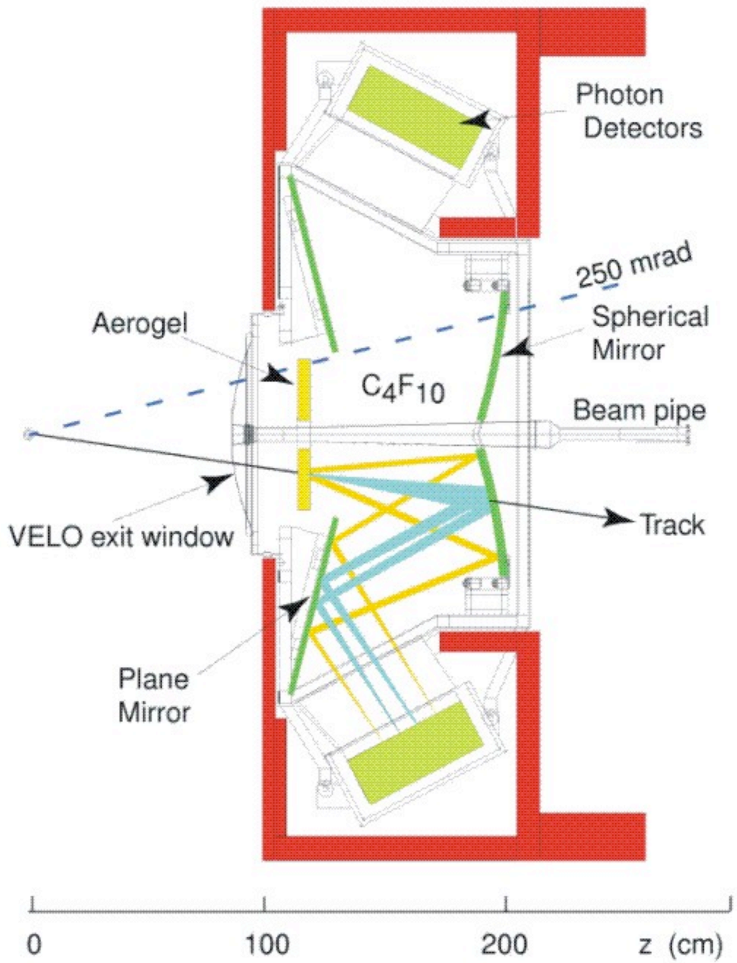


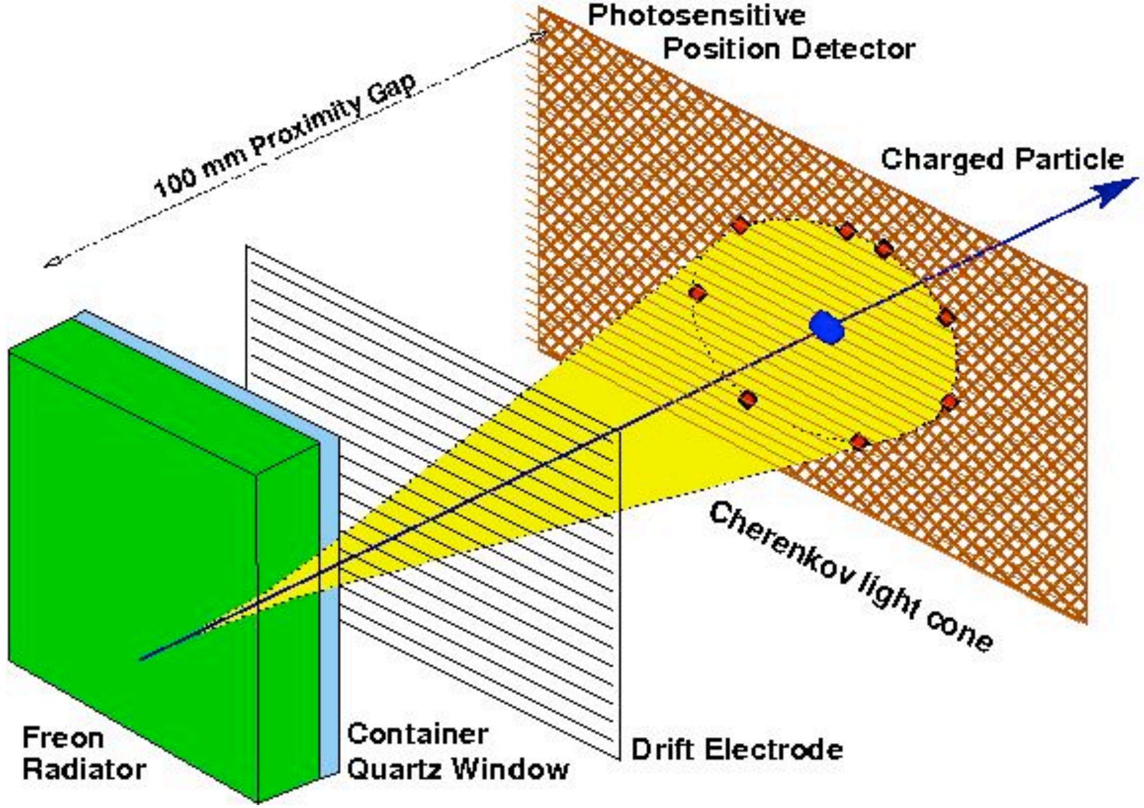
Test beam was vital to get detector ready!!!

Detectors for particle identification and triggering

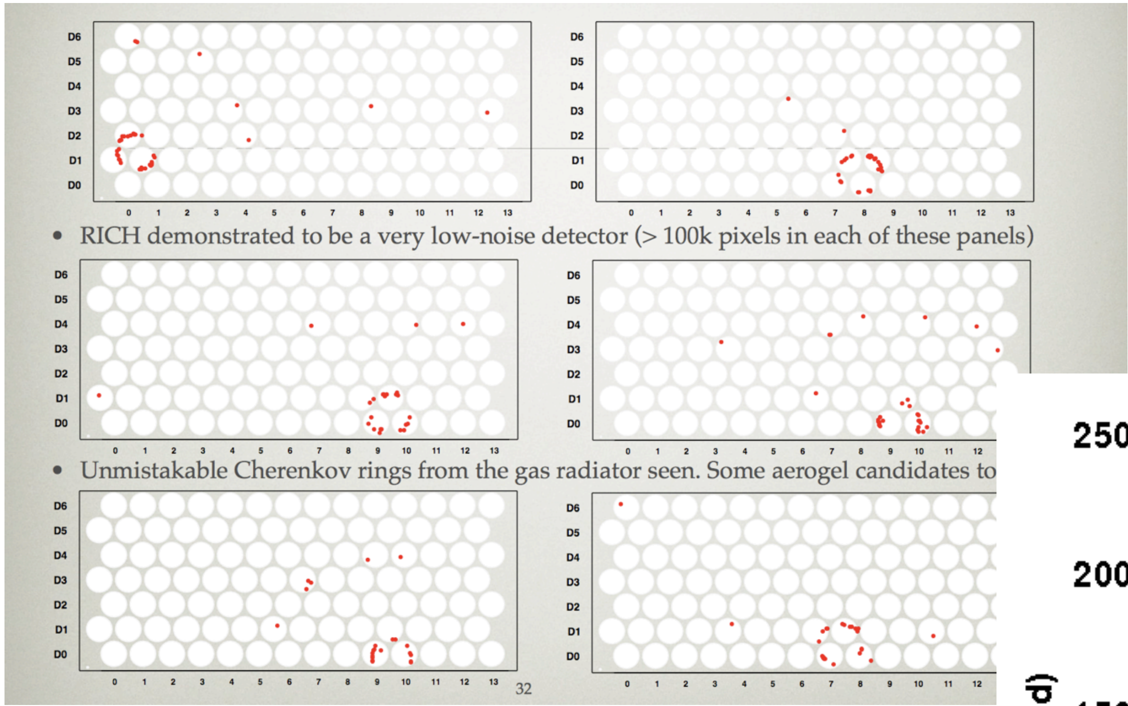
PID: Cherenkov detectors

- Ring Imaging Cherenkov detector (RICH) as used in LHCb. Principle:

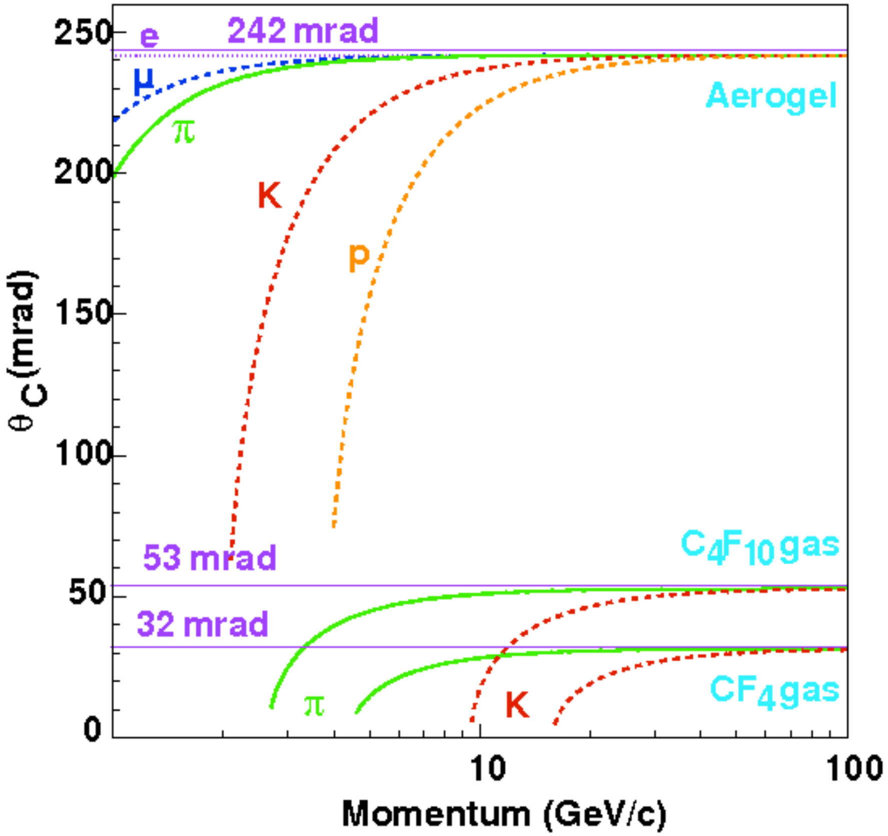




The LHCb RICH



To use the Cherenkov information for particle ID:
Measuring angle under which the photon is emitted



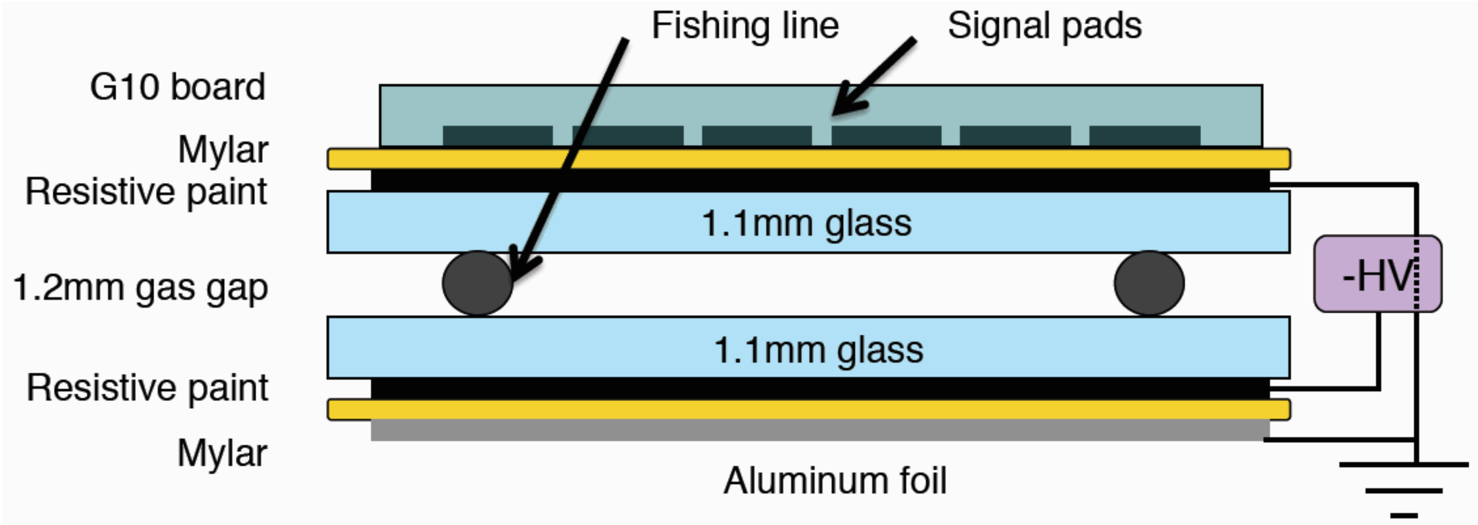
LHCb RICHs:

➙ 2 detectors

➙ 3 radiators

- Aerogel
- C_4F_{10}
- CF_4

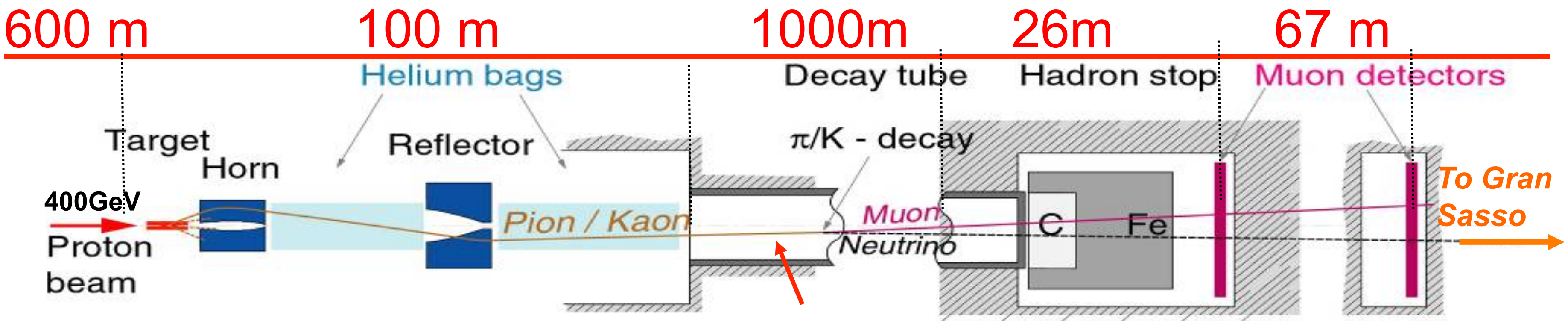
Triggering: Resistive plate chambers



- Gas detector without wires: gas volume between two plate with high resistivity(~10^{12} Ωcm), covered with a thin resistive layer (~1 MΩ/cm^2)
- High voltage (5 - 10 kV): a passing particle initialises an avalanche, which is quenched due to the high resistivity

Very good time resolution: ~50 - 100 ps: commonly used as trigger detectors.
Simple construction even for large areas.
con: only low particle rates possible, choice of material important

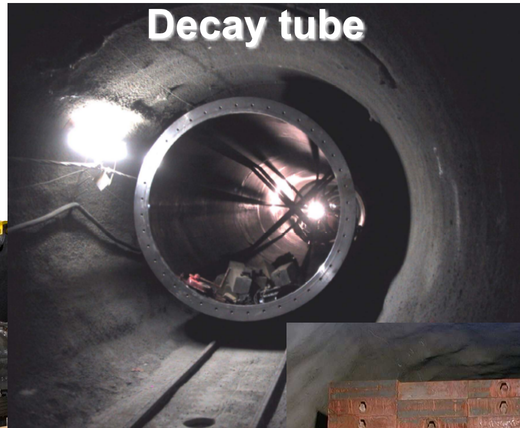
CNGS: beam of μ neutrinos

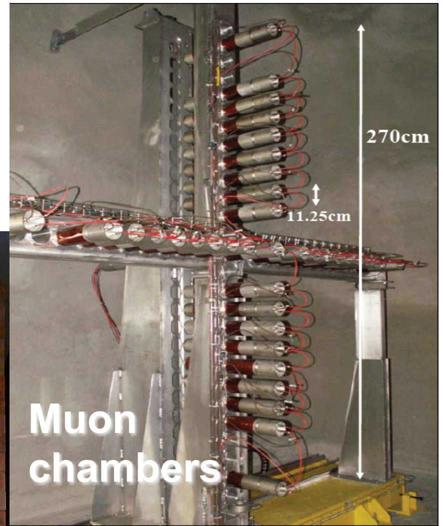


vacuum

$4.5\ 10^{19}$ p.o.t. /year

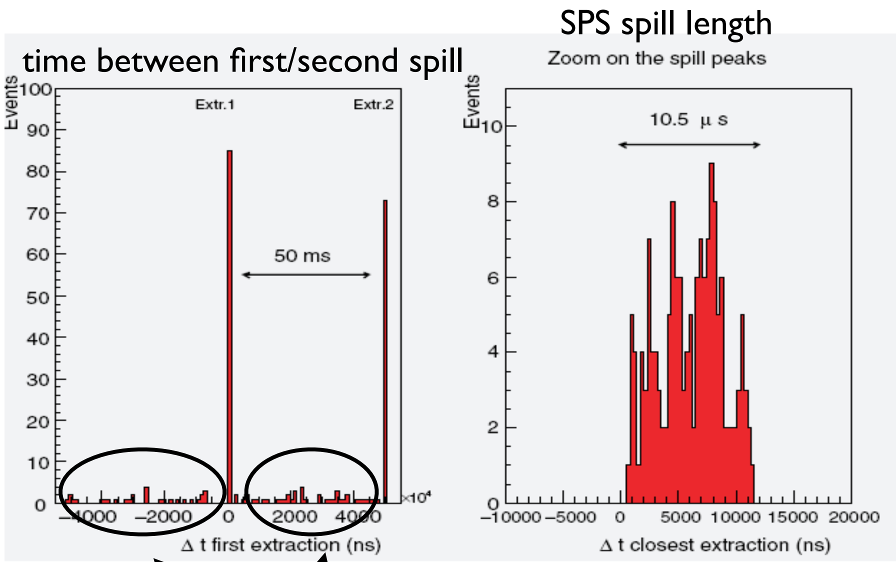
Ø at
GS=2km
3.2° angle





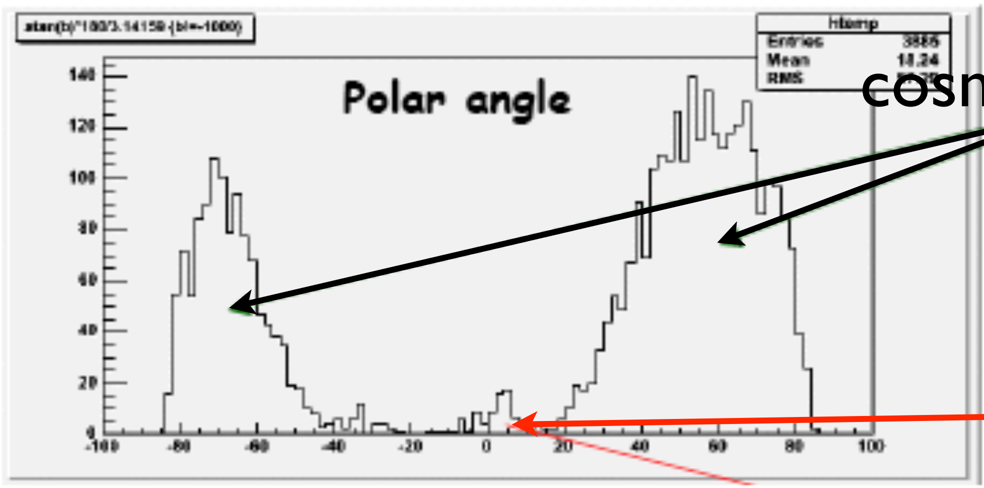
- **Civil engineering completed (June ’03)**
- **Hadron stopper and decay tube installed (June ’04)**
- **Target section completed in 2006 (first CNGS beam in August 2006)**

CERN neutrinos to Gran Sasso

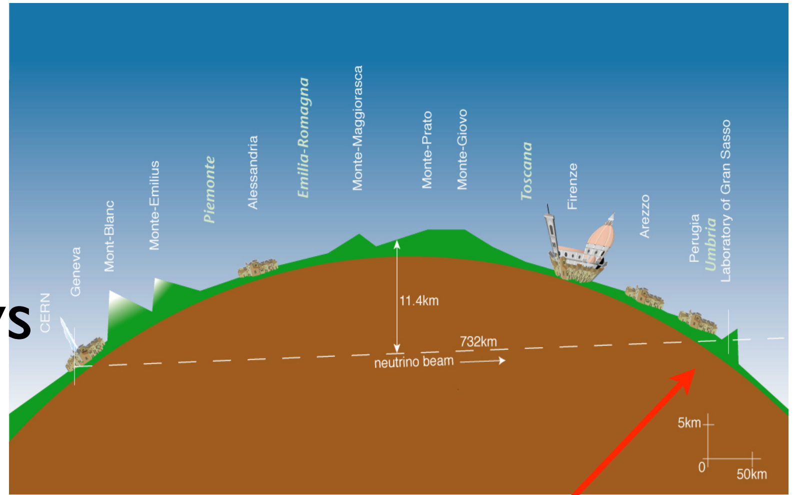


cosmic rays

Cross-check and **selection of events** from CERN by OPERA is done using **timing information** → spill structure of the SPS should be seen!

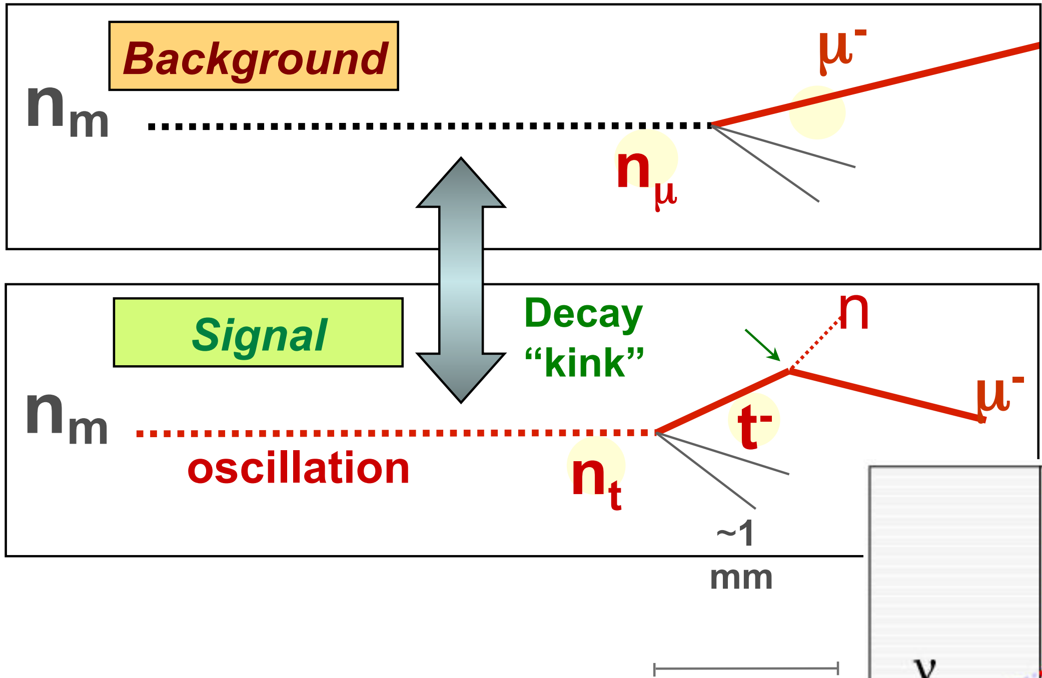


cosmic rays

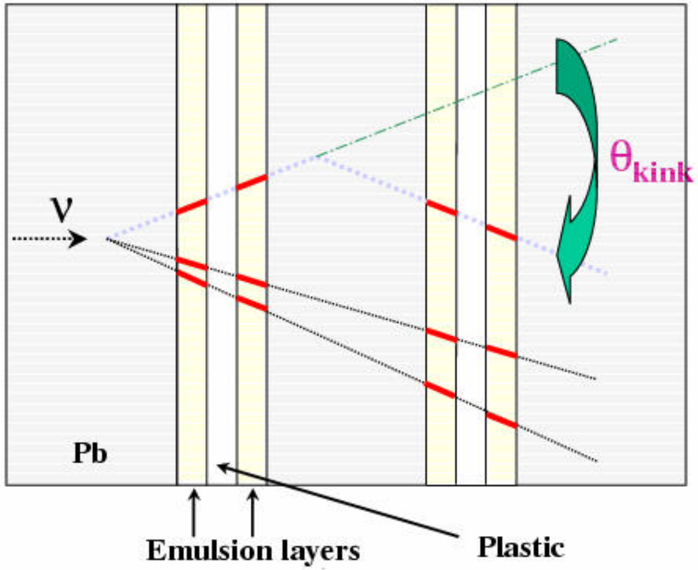


Signal events coming 3.5 deg from below (...from CERN!)

OPERA: detecting τ neutrinos



OPERA concept:
observe CC interactions in lead target (1 mm thick plates) and detect τ's in emulsion films
(~155000 bricks, ~10x10x20cm3, 57 emulsion layers each)



What the brick cannot do:

- trigger for a neutrino interaction
- muon identification
- momentum/charge measurement

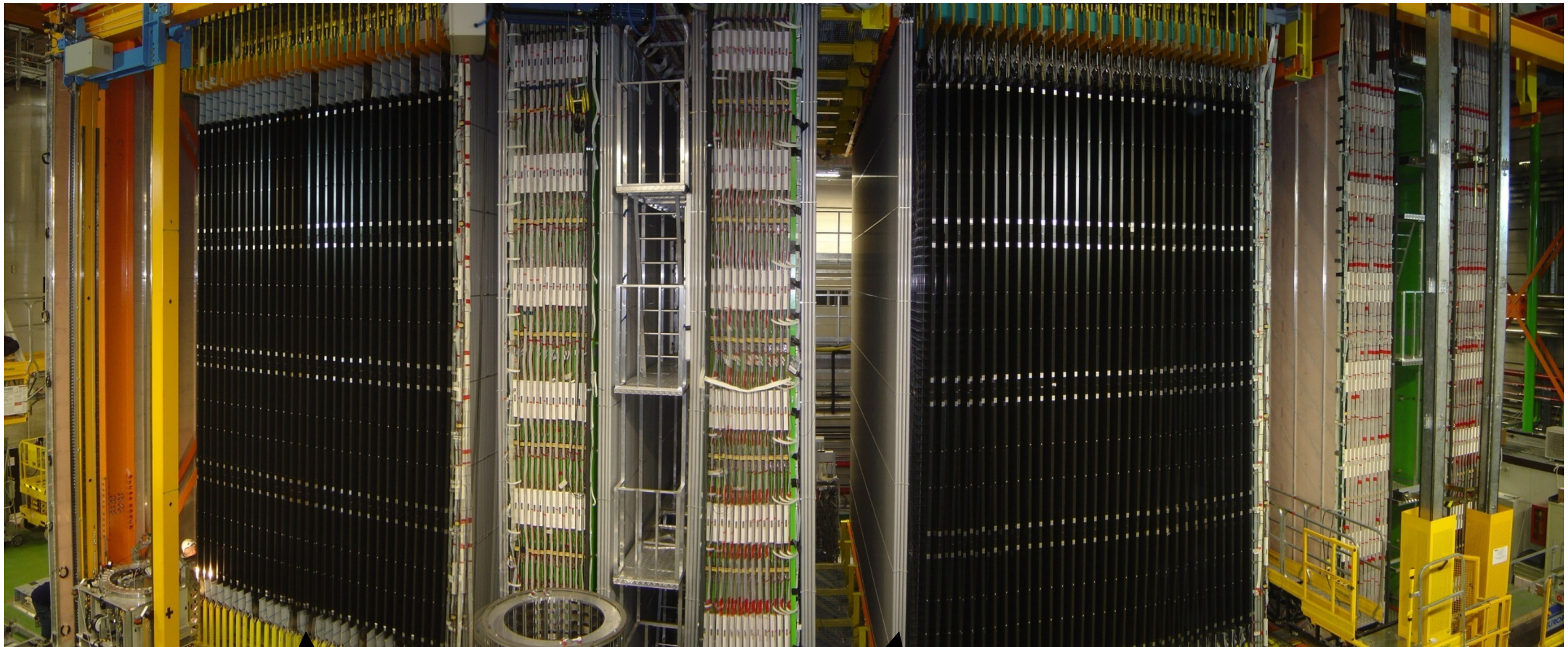
→ **need a hybrid detector**

sdsd

20 m

super module 1

super module 2



10 m

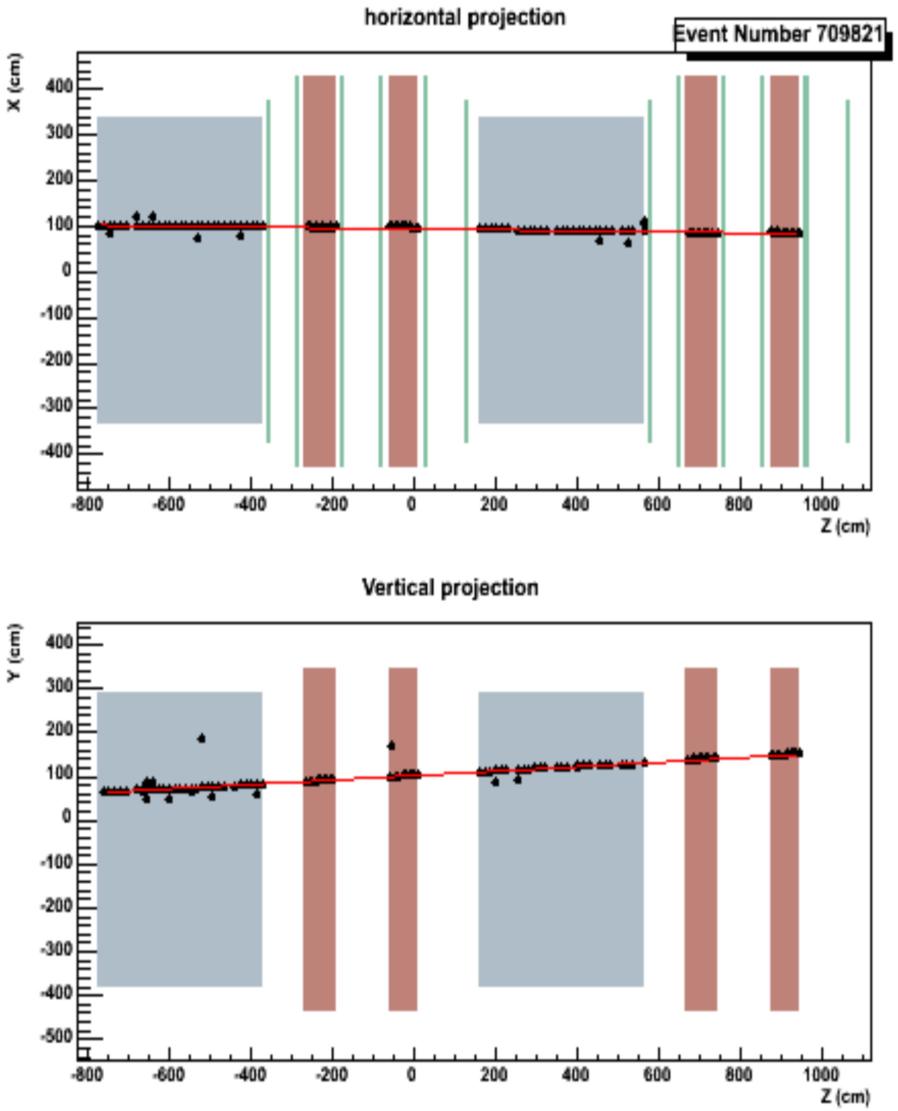
bricks & target tracker
(plastic scintillator strips)

drift tubes

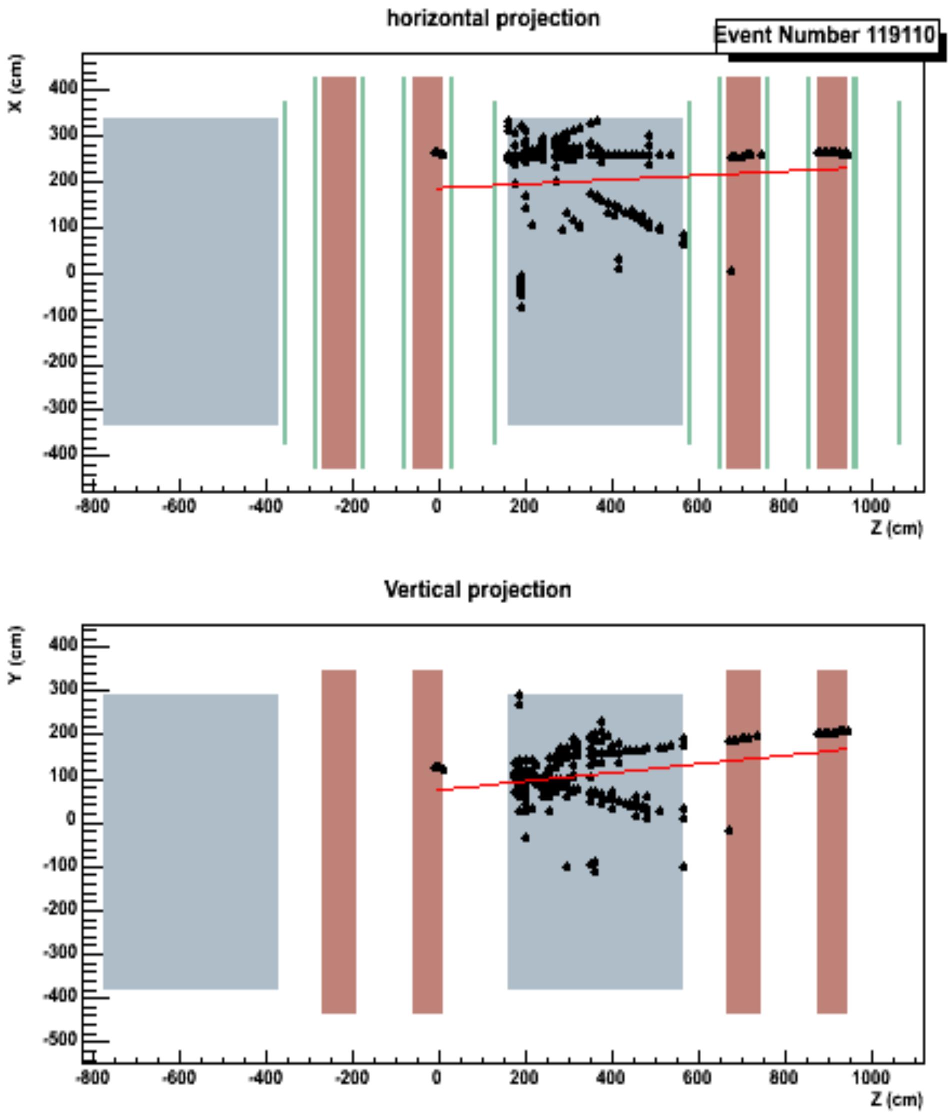
muon spectrometer
(magnet and RPCs)

OPERA events

CC event originated upstream of the detector (BOREXINO, rocks)

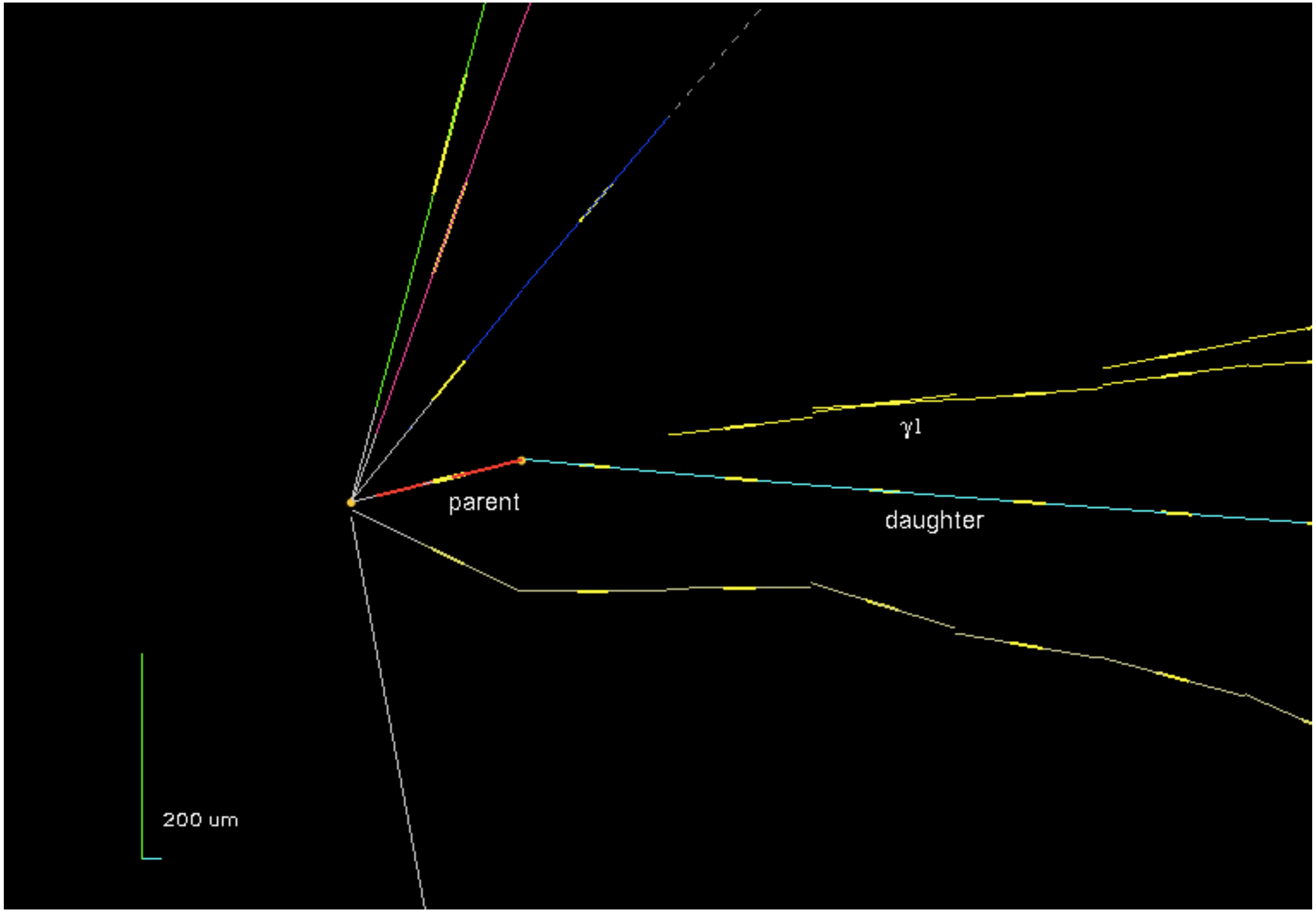


CC event originated in the first magnet



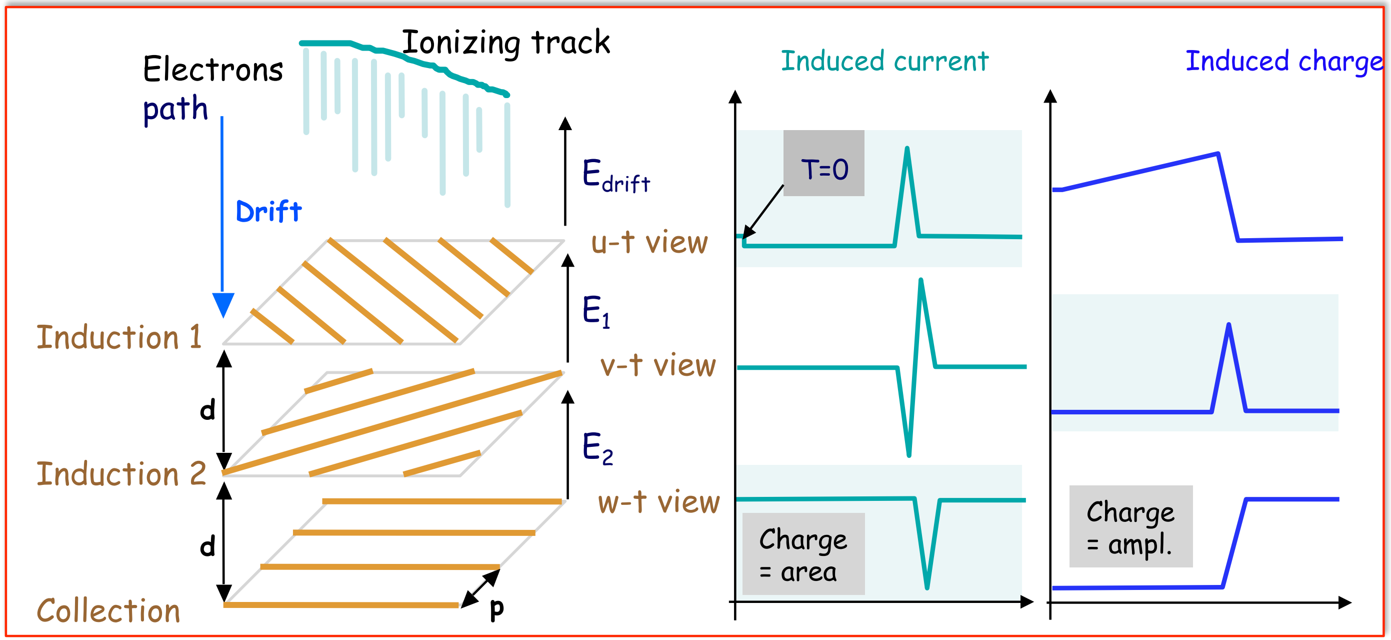
OPERA: first tau event in a brick!

- 2010



The ICARUS Liquid Argon TPC

ICARUS is a second detector at the Gran Sasso laboratory, also looking for neutrino oscillation (and neutrino velocity)



Electrons from ionising track are drifted in LAr by E_{drift}.
They traverse two transparent wires arrays (Induction 1 & 2) and are finally collected by a collection plane.
At 500 V/cm a 1.5 m drift length corresponds to a drift time of 1. ms (electron drift velocity, $v_{drift} \sim 1.55$ m/ms).
The intrinsic bubble size is $\sigma_D[mm] = 0.9 \sqrt{(t_D[ms])}$.
For 1.5 m drift $\sigma_{D\ max} = 0.9$ mm, tiny with respect to 3 mm wire pitch.

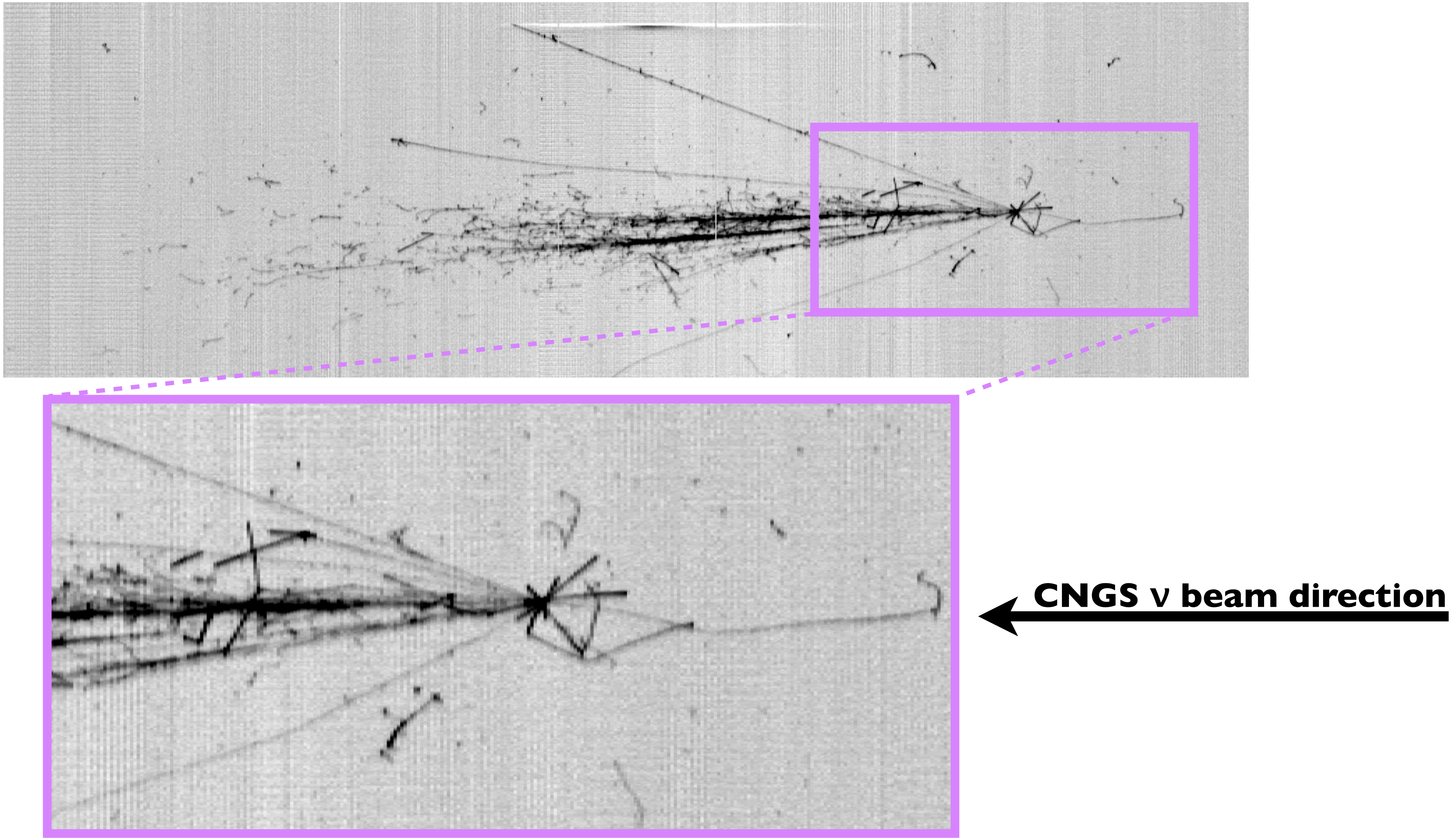
ICARUS - 600 tons of LA

Positioned in one of the huge LNGS underground halls

600 tons of liquid argon, the so called T600, has started data taking in 2010

Beautiful events!

- Neutrino interactions in ICARUS

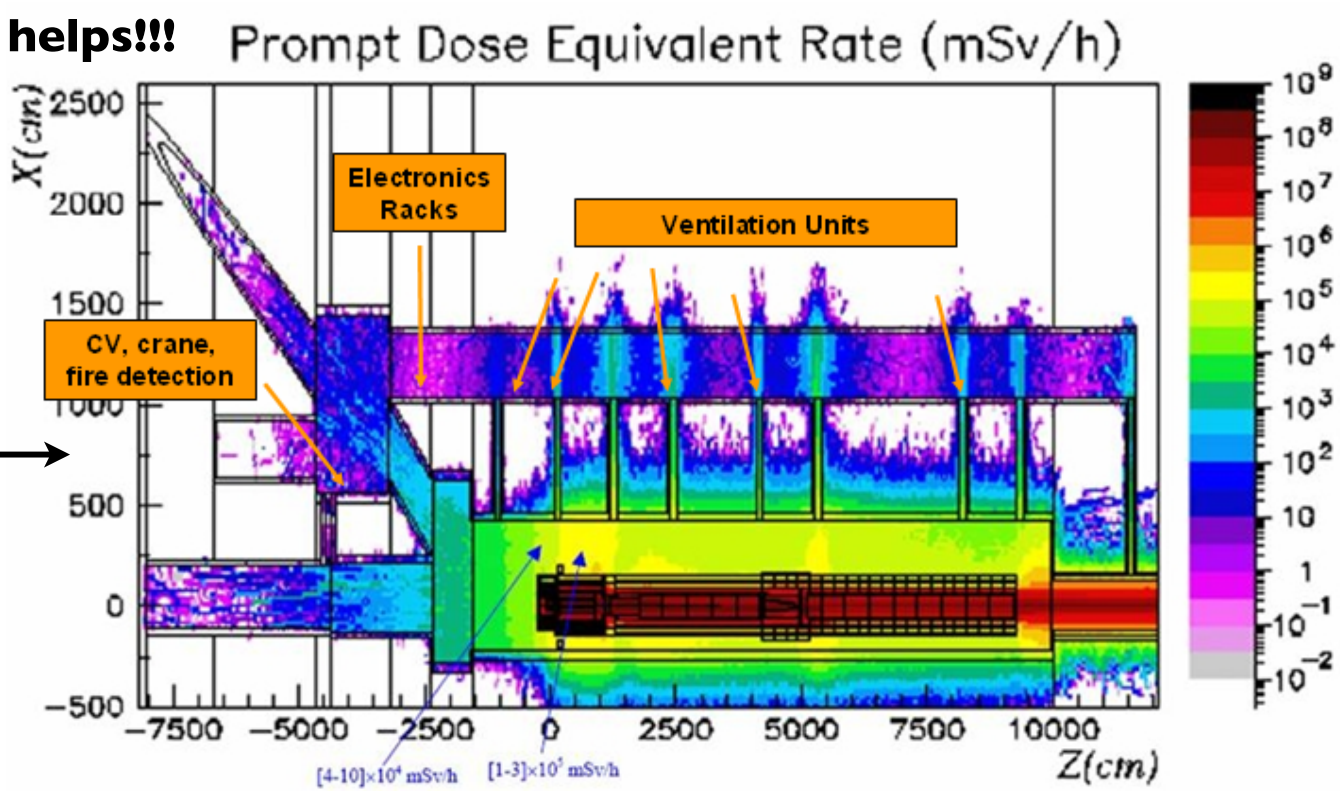


A lesson for experiments/detectors

- CNGS commissioning run stopped 5 days earlier failure of electronics of ventilation units because of **radiation damages**

- **A good simulation helps!!!**

Simulation of the radiation levels in the CNGS target zone →



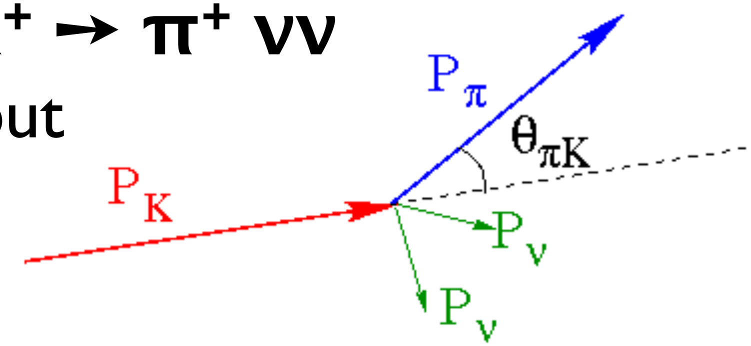
M. Sentis et al. AB/ATB, CERN-OPEN-2006-09, 2005

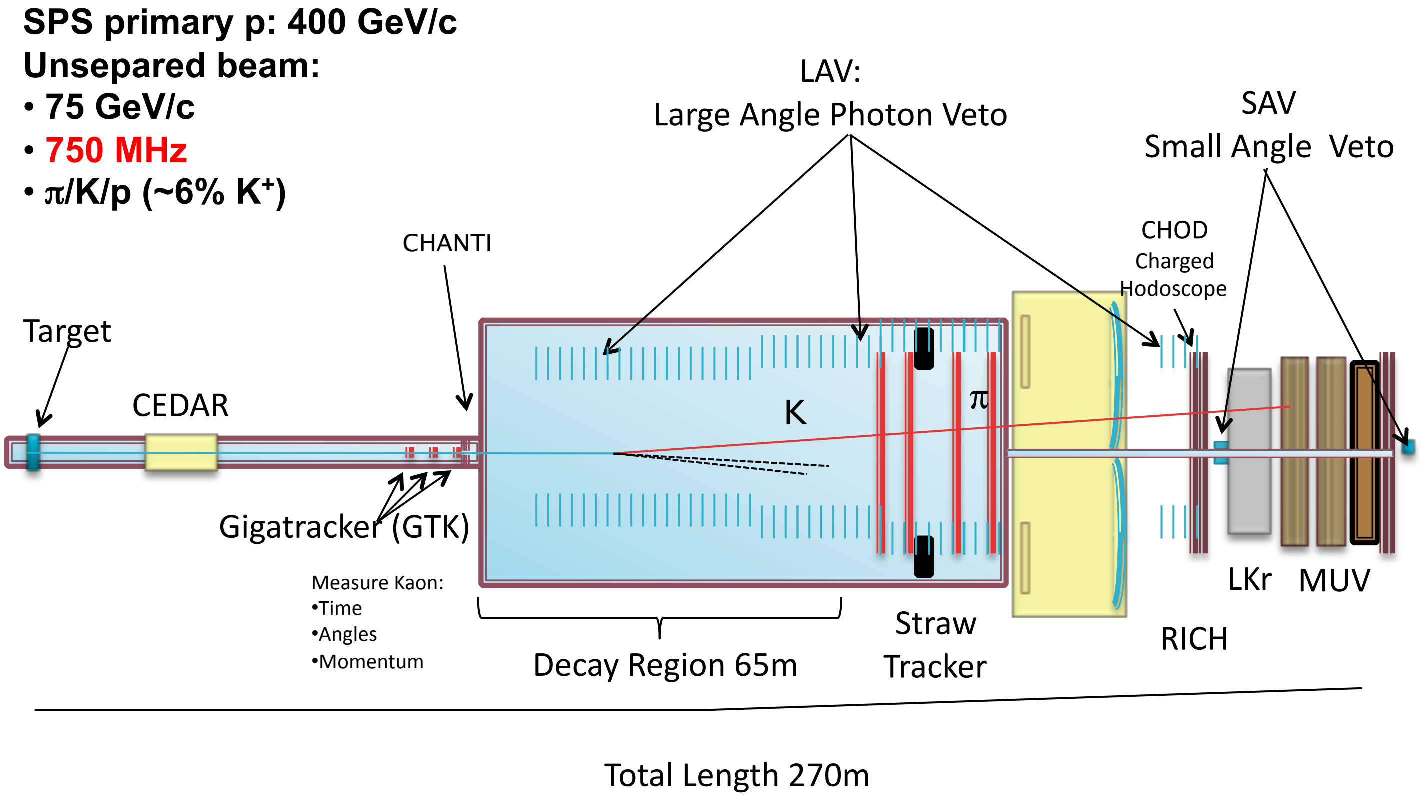
LHC equipment, experiments and detectors have been checked with irradiation tests and beam tests ✓

N62: experiment to measure rare kaon decays

Goal of the experiment:
Measure rate of rare kaon decay $\mathbf{K^+ \rightarrow \pi^+ \nu\nu}$
Rate in Standard Model: ~O(10^{-6}) but much enhanced when there is physics beyond the SM

Main background
$\mathbf{K^+ \rightarrow \pi^+ \pi^0}$





Beam line:
- CEDAR: K ID
- Gigatracker: beam particle ID
- CHANTI: Charged particle veto

Detector region:
- pion tracks: straws
- particle ID: LKr, RICH
- muon rejection: MUV
- photon rejection: LKr, LAV, SAV

- K+ rate: 11 kHz

Instead of a summary

- Build your own detector, get experience and fun!

STYX - Straw Tube Young student eXperiment

STYX

Welcome to STYX

Experimental Structure

- Gas System
- Trigger System
- Readout system
- Reconstruction and Analysis

Goals

Status

STYX setup

The STYX experiment is based on drift time measurement in gas detectors to reconstruct charged cosmic tracks. The basic constrain on the experimental setup is given by the tracking modules. We use straw tube gas detectors that were developed for the ZEUS Straw Tube Tracker (STT).

Two of these modules allow not only a position measurement but also the reconstruction of angular distributions of the tracks. These modules are flooded by ArCo2 provided by a supporting gas system. For the readout system the trigger signal of two photomultipliers is used. These PMTs collect the light signal of two scintillator plates surrounding the two modules.

The collected data is interpreted in a software environment in order to reconstruct track objects and visualize them for a better understanding.

structure.txt · Last modified: 2011/05/06 18:16 by Markus Jüngst

E.g. see TRT student experiment, see http://brock.physik.uni-bonn.de/styx/doku.php?id=structure

- Build your own detector, get experience and fun!

Literature

Text books:

- **C.Grupen: Particle Detectors, Cambridge UP 22008, 680p**
- **D.Green: The physics of particle Detectors, Cambridge UP 2000**
- **K.Kleinknecht: Detectors for particle radiation, Cambridge UP, 21998**
- **W.R. Leo: Techniques for Nuclear and Particle Physics Experiments, Springer 1994**
- **G.F.Knoll: Radiation Detection and Measurement, Wiley, 32000**
- **Helmuth Spieler, Semiconductor Detector Systems, Oxford University Press 2005**
- **L. Rossi, P. Fischer, T. Rohde, N. Wermes, Pixel Detectors – From Fundamentals to Applications, Springer Verlag 2006**
- **Frank Hartmann, Evolution of Silicon Sensor Technology in Particle Physics, Springer Verlag 2009**
- **W.Blum, L.Rolandi: Particle Detection with Drift chambers, Springer, 1994**
- **G.Lutz: Semiconductor radiation detectors, Springer, 1999**
- **R. Wigmans: Calorimetry, Oxford Science Publications, 2000**

web:

- **Particle Data Group: Review of Particle Properties: pdg.lbl.gov**

THANKS!!!!!

- Many thanks to Ingrid Gregor, Klaus Desch, Werner Riegler, Daniel Froidevaux, Markus Jüngst and Barbara Warmbein who helped me preparing these lectures!